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DRAFT
ENVIRONMENTAL IMPACT STATEMENT

Waste Isolation Pilot Plant

Volume 1 of 2

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April 1979

U.S. DEPARTMENT OF ENERGY

DRAFT ENVIRONMENTAL IMPACT STATEMENT (DOE/EIS-0026-D)
WASTE ISOLATION PILOT PLANT
U.S. DEPARTMENT OF ENERGY

1. This draft Environmental Impact Statement (EIS) has been prepared by the U.S. Department of Energy (DOE) in compliance with the National Environmental Policy Act (NEPA) to assess the environmental impacts of constructing and operating a proposed waste isolation pilot plant (WIPP) for the disposal of defense transuranic nuclear wastes (TRU), experimental research and development with high level waste forms and for the potential disposal of up to a thousand spent fuel assemblies in an intermediate scale facility (ISF). The WIPP would be licensed by the Nuclear Regulatory Commission (NRC) should project licensing be authorized by the Congress.

2. The draft EIS is intended to serve as environmental imput into future decisions concerning construction phases of the proposed repository, inclusion of the spent fuel option, timing and specific location of the facility, and land withdrawal in Eddy County, New Mexico, if that site is chosen.

3. Analyses show that there are no significant radiological health impacts resulting from the alternatives considered, and that there are no clear environmental bases for choosing among alternatives other than the alternative of no action which is considered unacceptable in the long term.

4. Seven alternatives are covered in the draft EIS including: no action, alternatives to TRU-waste disposal, alternatives for the intermediate-scale facility, alternative time schedules and potential alternative locations. The range of options was intended to cover a reasonable envelop within which governmental decisions can be made.

5. Comments on the EIS are requested by July 6, 1979 from the Departments of Agriculture; Commerce; Defense; Justice; Labor; State; Housing and Urban Development; Health, Education, and Welfare; Interior; and Transportation; the Advisory Council on Historic Preservation; National Science Foundation; Nuclear Regulatory Commission; U. S. Arms Control and Disarmament Agency; Interstate Commerce Commission; Water Resource Council; the fifty states; and other organizations and individuals who are known to have an interest in this activity.

6. The statement has been sent to the Environmental Protection Agency and an announcement of its availability has been submitted to the Federal Register.

Note: Additional information regarding this statement can be obtained from and comments should be sent to Mr. Eugene Beckett, WIPP Project Office, Mail Stop B-107, Department of Energy, Washington, D. C. 20545, telephone 301/353-3253.

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Volume 1 of 2

April 1979

U.S. DEPARTMENT OF ENERGY
Washington, DC 20545

Foreword

In furtherance of its responsibilities to develop and implement methods for the safe and environmentally acceptable management of radioactive wastes, the U.S. Department of Energy (DOE) is considering five major decisions:

1. Whether to pursue the construction of the proposed Waste Isolation Pilot Plant (WIPP), a mined repository for the disposal of transuranic wastes, with an initial period of retrievable emplacement

2. Whether the WIPP should include an intermediate-scale facility in which up to 1000 assemblies of spent fuel from commercial electricity-generating reactors would be disposed of, with an initial period of retrievable emplacement

3. Whether the WIPP should include a research-and-development facility in which experiments with all types of nuclear waste, including high-level waste, can be performed

4. What the timing and location of the WIPP should be

5. Whether to commit land now for a potential repository site in Eddy County, New Mexico

Pursuant to its responsibilities under the National Environmental Policy Act of 1969 (42 U.S.C. 4321 et seq.), the DOE has prepared this document as environmental input for the foregoing decisions. It also may be used as input for subsequent decisions by the DOE and other Federal agencies with respect to the site of the proposed facility.

Should it be decided to pursue the construction of the WIPP as a combined transuranic-waste repository, intermediate-scale facility, and research-and-development facility in New Mexico, that decision would not be irreversible. Consultations with State and local officials would take place during the preconstruction phase; comprehensive reviews of site suitability would be undertaken before each major step in repository construction; and if the WIPP is licensed as proposed by the Interagency Review Group on Nuclear Waste Management, authorization from the U.S. Nuclear Regulatory Commission would be required before repository construction.

All waste emplaced will be retrievable or actually removed; transuranic waste will be retrievable for 10 years, spent fuel will be retrievable for 20 years, and experimental waste will be removed when the experiments are completed.

This environmental impact statement does not analyze the permanent disposal of high-level waste other than the limited quantity of spent fuel in the intermediate-scale facility. Aside from that spent fuel, high-level waste will appear at the WIPP only for use in experiments that will examine the interactions between solidified high-level waste and the geologic burial medium; these experiments will build a base of empirical data for later decisions about a system of repositories for the disposal of high-level waste. The high-level waste used in

experiments will be removed after the experiments are done. Any future proposal to modify this approach would require further environmental review, state and public input, and licensing amendments.

This document is concerned only with decisions concerning a transuranic-waste repository, an intermediate-scale facility, and associated experiments. To provide a sufficient basis for these decisions, it also analyzes the radiological consequences of waste transportation and processing. Nevertheless, it is not intended to provide an environmental analysis to support decisions on actual routes or methods for transporting material to the repository or to support decisions on the construction of facilities for processing waste destined for the repository. The environmental implications of these decisions will be addressed in subsequent documents.

This environmental impact statement is arranged in the following manner: Chapter 1 is an overall summary of the analysis contained in the document. Chapters 2 through 4 set forth the policy objectives of the national waste-management program and analyze the full spectrum of reasonable alternatives for meeting these objectives, including the WIPP. Chapter 5 presents the interim waste-acceptance criteria and waste-form alternatives for the WIPP. Chapters 6 through 13 provide a detailed description and environmental analysis of the WIPP repository and its proposed site. Chapter 14 describes the interactions that have taken place with Federal, State, and local authorities and with the general public in connection with the repository. The appendices contain data and discussions in support of the material in the text.

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1 Summary

1.1 WASTE-MANAGEMENT POLICY LEADING TO THE PROPOSED WASTE ISOLATION PILOT PLANT

The proposed Waste Isolation Pilot Plant (WIPP) is part of the national program for the permanent disposal of radioactive waste. It stems from two decades of analytical, laboratory, and field study and from a recent reassessment of waste-management policy that has recommended a unified program to the President.

Large quantities of radioactive waste have resulted from the production of nuclear weapons as part of the U.S. defense effort. This waste includes both high-level waste (HLW) and transuranic (TRU) waste, defined in the main text of this document. The earliest decision on managing these wastes was made in the mid-1940s: to store high-level waste as liquids in tanks and to bury other waste in trenches. In the mid-1950s a committee of the National Academy of Sciences suggested salt formations for the permanent disposal of high-level waste. Studies of salt, including experiments in a salt mine in central Kansas, led to a 1970 proposal to establish an HLW repository in that mine; this proposal, however, foundered on a variety of technical and political problems.

After the Kansas site was given up, there was a renewed examination of possible repository sites, still primarily for high-level waste. Progressive elimination of less desirable sites led to the bedded salt of southeastern New Mexico and to the WIPP reference site described later in this document. In 1975 the WIPP mission was narrowed--only TRU waste from U.S. defense programs was to be accepted--and work started on a conceptual design for a repository at that site.

In the meantime, studies concerned with repositories for spent fuel from commercial reactors and other high-level waste continue under the National Waste Terminal Storage (NWTS) program. This program is considering sites in other regions and in rocks other than salt, such as basalt and shale.

A comprehensive review of the overall national program, started in 1977, has led to recent (March 1979) recommendations by a presidentially established Interagency Review Group (IRG) on Nuclear Waste Management. The Interagency Review Group found (1979, p. 15) that the primary objective of waste-management planning and implementation is to provide assurance that "existing and future waste from military and civilian activities (including discarded spent fuel from the once-through nuclear power cycle) can be isolated from the biosphere and pose no significant threat to public health and safety." In order to meet this long-term programmatic objective, the following near-term objectives have been derived from the historic waste-management program and its reassessment by the Interagency Review Group:

1. To meet stated U.S. Government intentions for early removal of the TRU waste stored at the Idaho National Engineering Laboratory.

2. To use existing opportunities, if they are adequate and acceptable, to advance waste-management technology and to dispose of existing wastes.

3. To emphasize work at sites that may realistically be considered for waste disposal.

4. To proceed by deliberate steps in a technically conservative manner.

5. To build a licensed full-scale TRU-waste repository in advance of HLW repositories, thus gaining experience in designing, analyzing, and operating repositories and in obtaining approval from the U.S. Nuclear Regulatory Commission and other regulatory bodies.

6. To build a licensed intermediate-scale facility for the disposal of spent fuel from commercial reactors in advance of HLW repositories, thus gaining further experience in designing, analyzing, and operating repositories and in obtaining approval from the U.S. Nuclear Regulatory Commission and other regulatory bodies.

7. To combine compatible facilities, where suitable, in order to avoid unnecessary costs and to assist in integrating research-and-development programs.

To meet these near-term objectives, the Department of Energy is considering several alternative plans. This document examines these plans and compares their impacts to those of a reference plan, the WIPP, which has been the most thoroughly investigated of the alternatives. A discussion of the WIPP appears in the next section.

1.2 THE WIPP REFERENCE CASE

Intended to meet the seven policy objectives as thoroughly and quickly as possible, the WIPP reference repository has been designed to accomplish a three-part mission:

1. The WIPP is to be a licensed, full-scale repository for the permanent disposal of TRU waste. It will receive this waste from the Idaho National Engineering Laboratory (INEL). The initial underground excavation will create a 100-acre area that can hold all the TRU waste now stored at the INEL as well as the waste expected there through 1990; future expansion of the repository can provide an area of 2000 acres for the disposal of TRU waste from other sites. All the TRU waste to be received at the WIPP will have been produced in the U.S. defense program. The waste will be emplaced in such a manner that it can be retrieved during a 10-year period if it becomes necessary to do so.

2. The WIPP will contain a 20-acre underground area for research and development. There experiments performed with all types of nuclear waste will answer technical questions about the disposal of waste, including high-level waste, in salt. All the waste used in these studies will be removed when the experiments are over.

3. The WIPP will contain a 20-acre underground area for the permanent disposal of spent-fuel assemblies removed from nuclear reactors. Called an "intermediate-scale facility" by the Interagency Review Group, this part of the WIPP will receive as many as 1000 assemblies

emplaced in such a manner that they can be retrieved for 20 years if necessary, but without the expectation of doing so.

A proposed site for the WIPP reference repository has been investigated. Under the WIPP conceptual design, all three parts of the mission can be accomplished at this site.

Characteristics of the reference site

The WIPP reference site is in southeastern New Mexico, about 25 miles east of Carlsbad. Its area is 18,960 acres, all Federal and State land.

The site is on a plateau east of the Pecos River, an area of rolling sand-covered hills and sand dunes with desert vegetation. The land is used for grazing at a density of about six cattle per square mile.

Thirteen people live within 10 miles of the center of the proposed site; approximately 94,000 people live within 50 miles. Basic industries in the area are mining, manufacturing, and agriculture. Tourism is important because of the nearness of the Carlsbad Caverns National Park (41 miles west-southwest of the site).

Southeastern New Mexico is arid. There is a wet season in late summer, but the total rainfall at the site is only about 13 inches a year. Winds are from the southeast throughout the year, although the storm winds of winter and spring tend to come from the west.

Geology

The site is in the north-central part of the Delaware basin, a region in which evaporation in a shallow Permian sea deposited about 3600 feet of evaporites. A repository at this site would be built in the nearly pure salt of the Salado Formation, itself almost 2000 feet thick, with mined disposal levels 2100 and 2700 feet below the surface.

Potash minerals and hydrocarbons (oil and gas) are important resources in the region. The former occurs sporadically in a layer 800 to 1000 feet below the surface, the latter in various strata from 4000 to 14,000 feet below the surface. There appear to be no economic reserves of crude oil at the site, but there is natural gas amounting to about 0.02% of U.S. reserves. On the other hand, the Carlsbad potash district is the principal domestic source of sylvite and langbeinite for fertilizers; the langbeinite of the area may be unique in the free world. To protect the repository it will be necessary to deny the extraction of some of these resources. There will be, however, only a temporary denial of access to approximately one-third of the natural gas, three-quarters of the langbeinite, and all of the sylvite at the reference site.

The site is in an area of low seismicity.

Hydrology

The Pecos River is 14 miles to the southwest, but there is no integrated drainage leading from the site to the river. The principal groundwater aquifer of the region is the Capitan Formation about 10 miles to the north. Aquifers at the site itself yield little water, and it is of low quality.

Underneath the salt-bearing formations, there are about 3000 feet of rocks bearing brackish water. This water flows slowly toward the northeast with some connections to the base of the Capitan.

The salt-bearing formations contain no circulating groundwater, although isolated pockets of pressurized brine have been found below the Salado.

Above the salt-bearing formations there are two beds of dolomite that bear water sometimes used for stock. This water flows to the southwest, finally discharging in brine springs along the Pecos River.

Underground dissolution of salt is still an active process in the region. At the site itself dissolution has removed some salt from above the Salado, but essentially no Salado salt. The dissolution front at the top of the Salado is about 2 miles west of the center of the site and is advancing toward the east at a rate estimated to be 6 to 8 miles per million years.

The possibility of dissolution at the base of the evaporites has been under investigation because this process appears to be active to the south in Texas. It does not appear to be active within 10 miles of the site.

The plant and its operation

The reference repository consists of both surface and underground facilities, including a waste-handling building, an underground-personnel building to support underground construction, an administration building, four shafts to the underground area, underground openings at two levels for waste storage, and various support structures. There will be a storage pile for mined rock, an evaporation pond for sewage-treatment effluents, a disposal area for construction spoils, and a landfill for sanitary wastes.

At the site, railcars and trucks will be unloaded within a waste-handling building, where the waste will be prepared for movement underground. Of the two storage and disposal levels underground, the upper one, 2100 feet below the surface, will be used for the disposal of contact-handled TRU waste; the lower level, 2700 feet underground, will be used for the disposal of remotely handled TRU waste. The lower level will also be used for demonstrating the disposal of spent fuel and for experiments with high-level waste. Both levels will be in the Salado Formation, a thick layer of bedded salt that extends from 860 to 2836 feet below the surface at the center of the site.

Construction of the facility will take 42 months, and the plant is designed for a useful life of at least 30 years.

Operating at three shifts per day, the reference repository can handle 1.2 million cubic feet per year of contact-handled TRU waste, 10,000 cubic feet per year of remotely handled TRU waste, 350 canisters per year of spent-fuel assemblies, and 100 canisters per year of high-level waste for experiments.

The area set aside for potential underground storage operations is about 2000 acres; the remaining acreage will provide a 2-mile-wide buffer zone around the underground operations area. The initial excavation at the upper (contact-handled waste) level will take place in about 170 acres; about 100 acres will be used as waste-disposal rooms. Later mining could allow about 70

million cubic feet of waste to be stored on this level. The lower mine level will have three separate areas of about 10 to 20 acres each for the storage of remotely handled TRU waste, for the spent-fuel demonstration, and for high-level-waste experimentation. Service areas will take up additional acreage on both levels.

1.3 ALTERNATIVES

The reference site in southeastern New Mexico and the plant design formulated for that site are but one of a number of possible alternatives for meeting the WIPP mission. Because they are the most completely analyzed of these alternatives, they are used as the WIPP reference case. All other alternatives are evaluated relative to the reference case. These alternatives include no action at all, alternatives for TRU-waste disposal, alternatives for the intermediate-scale facility (ISF), alternative time scales, and alternative locations.

One conceivable alternative for the ISF is a stand-alone facility, one that is only an ISF and satisfies no other parts of the WIPP mission. This is not considered an attractive alternative because of its high cost relative to other alternatives, because of its limited achievement of program objectives, and because it might foreclose the use of a site that could otherwise be used for a full-scale repository.

Alternative time scales and locations are interconnected. The National Waste Terminal Storage program is considering other possible locations for waste disposal, but no other site has received the kind of detailed study the New Mexico site has. Delay would give time for such study and permit alternative locations to be considered.

The full set of alternatives considered in this document is as follows:

1. No action. No ISF is built, and TRU waste remains stored at the Idaho National Engineering Laboratory and elsewhere as it is now.

2. The WIPP reference repository in southeastern New Mexico.

3. The WIPP reference repository, but without the ISF.

4. Disposal of TRU waste in the first available HLW repository. By 1982 or soon thereafter, sites in the Gulf interior region salt domes and Hanford basalt should be available for consideration. An HLW repository would be built at one such site, and TRU waste would be put into it. The initial retrievable-storage phase of the repository would take the place of the ISF.

5. Delay of alternative 2. By 1982 or so, the WIPP may also have the choice of dome salt and basalt sites.

6. Delay of alternative 3, similarly.

7. A longer delay. By 1985 or somewhat thereafter, sites may also be available in granite, tuff, or shale for an HLW repository as in alternative 4.

1.4 ENVIRONMENTAL EVALUATION OF ALTERNATIVES

Alternative 2 is the most thoroughly analyzed of the seven and therefore constitutes the reference case for this evaluation. The costs and impacts of HLW repositories, required for alternatives 4 and 7, are taken primarily from the DOE's draft generic environmental impact statement for the Management of Commercially Generated High-Level Waste. Consideration of alternatives 4 and 7 is made from two points of view: (1) the changes in impacts (usually increases) associated with expanding the mission of the HLW repository and (2) the changes in impacts (usually decreases) in having one repository rather than two.

Alternative 1: No action

If neither the WIPP reference repository nor any of its alternatives becomes available, TRU waste will have to remain at its present storage sites, and spent fuel will remain in storage pools. In the short term, the radiological consequences of no action are small. At the INEL, for instance, exposures of no more than 3.6×10^{-6} rem per year could be expected. The population exposure from the operation of storage pools is estimated as less than 20,000 man-rem world wide.

In the long term, on the other hand, some natural events that might produce large exposures due to natural forces are quite probable. The INEL, for instance, is located at the edge of the Arco Volcanic Rift Zone, which has been active within the last 400,000 years and is likely to be the scene of future volcanic action.

Alternative 2: The WIPP reference repository

The most important physical impacts of alternative 2 are the removal of 980 acres of land from grazing and the denial of access to subsurface minerals. Probably the only land use that would be truly permanent would be the 30 acres used for storing mined salt. The important mineral reserve is langbeinite, a mineral used for fertilizer where chlorides cannot be used; an estimated 3% of the U.S. reserves of this mineral would be denied for perhaps several decades. Although langbeinite is useful, it is not essential to agriculture; substitutes for it exist.

The WIPP reference repository will cost $430 million (1978 dollars) to design, engineer, and build and $36 million a year to operate. Jobs created directly and indirectly will peak at about 3100 during construction and drop to 1100 during operation.

An accident of the extreme severity postulated in the transportation analysis could deliver a 50-year radiation-dose commitment that might reach 25% of the dose from natural background radiation.

During plant operation the most severe accident would be the drop of a spent-fuel canister in the mine shaft. The maximum individual (skin) dose to persons at the nearest off-site point would be 0.2% of the dose from natural background radiation.

After the WIPP ceases operation and is closed up, the expected release of radioactive material is zero. Nevertheless, if someone were to drill directly into the stored spent fuel 100 years later, the geologist on the drill crew could be exposed to a whole-body dose of 8.8 rem, 1.8 times the permissible occupational exposure for 1 year. The largest individual exposure from radioactivity carried by groundwater after a hypothetical breach of the repository is estimated to be an annual bone dose of 0.002 rem, 2% of the dose received from natural background radiation.

Alternative 3: The reference repository without an ISF

If no ISF is built in the WIPP, there will be little change in physical or socioeconomic effects: no change in land use, a 10% reduction in volume mined, and a cost reduction of a few percent. Transportation risks will be reduced because there will 8% fewer shipments; the consequences of the postulated accidents, if they occur, will be reduced by at least a factor of 2. Elimination of spent fuel will change the most severe operational accident to an underground fire, reducing maximum off-site individual exposures from 0.2% to 10^{-7}% of the dose received from natural background radiation.

In the long term, elimination of spent fuel drops the maximum individual exposure from drilling into the repository from 8.8 to 0.001 rem. The hypothetical exposure from groundwater-borne radioactivity decreases by roughly a factor of 25 to 50, dropping to less than 0.1% of background exposures.

Alternative 4: Combination with an HLW repository

In this alternative, there is no separate TRU-waste repository, and the initial retrievable-storage phase of the HLW repository takes the place of an ISF. The delay inherent in this alternative means that the TRU waste and the spent fuel remain longer in their present storage; leaving them there entails no significant impact or risk. The additional candidate sites to be considered are in dome salt and in basalt.

At the HLW repository, land use may be larger by about 25% with the addition of TRU waste, but combining the two repositories into one reduces the overall land use by 40%. The quantity of mined rock will increase at the HLW site and remain unchanged overall. It is believed that the use of a site other than the reference site in southeastern New Mexico will decrease interference with the use of mineral reserves.

The cost will increase at the HLW site by 4 to 10%, but will decrease overall. The number of workers will increase at the HLW site by 27 to 35%, but will decrease 10% overall.

Transportation routes will be longer to dome-salt sites and shorter to basalt sites than to southeastern New Mexico. The consequences of individual accidents will remain essentially unchanged.

There is no reason to expect any change in operational accident probabilities; overall population exposure will be increased because population densities are greater near prospective dome-salt and basalt sites.

In the long term, the expected release of radioactivity from all sites is the same: zero. Credible events or processes that might impair repository integrity differ with the site, and analyses of the consequences of such breaches at sites other than the one in New Mexico have not been performed. However, any such alternative site will have to be subjected to such analyses to meet the requirements of the National Environmental Policy Act, and any site that appears to offer significant risks from long-term releases will not be judged an acceptable site.

Alternatives 5 and 6: A TRU-waste repository built after consideration of additional sites

These alternatives amount to alternatives 2 and 3, delayed. During the delay, the TRU waste and spent fuel will remain in their present storage, with no significant consequences. The quantity of defense TRU waste will increase by about 2% per year.

The greatest consequence of delay is in the cost. To close out the present effort is estimated to cost about $3 million. To start the project up again, either at the reference site or elsewhere, will cost an estimated $280 million, much of this from inflation.

With or without an ISF, the costs and benefits of a TRU-waste repository in dome salt or basalt will differ from the costs and benefits in the bedded salt of southeastern New Mexico. Interference with mineral reserves will probably be reduced. Socioeconomic impacts and radiation exposures from accidents during operation will be changed by the greater population densities near the prospective dome-salt and basalt sites. Transportation routes will be longer to the dome-salt sites and shorter to the basalt sites than to southeastern New Mexico.

Finally, as in alternative 4, the long-term risks at alternative sites cannot now be assessed. Any such site must be subjected to the process required by the National Environmental Policy Act, and any site with a potential for significant risk will be rejected.

Alternative 7: Long delay

This alternative amounts to alternative 4, further delayed until sites in such media as granite, tuff, and shale can be evaluated. Not enough is known about these other media to evaluate them in comparison with bedded salt, dome salt, or basalt.

Environmental conclusions

All the predicted environmental impacts of the reference repository are small save two:

1. Use of the southeastern New Mexico site entails a long-term denial of access to 3% of the U.S. reserves of the mineral langbeinite.

2. Drilling at the site, if it occurs within about 100 years after the repository has been sealed, could expose members of the drill crew to doses above permissible occupational exposures.

In addition, it was found that delay and reinitiation of present efforts would cost on the order of $280 million.

It appears that the alternative of no action (alternative 1) is unacceptable in the long term and that there is no clear environmental basis for choosing among the remaining alternatives. The choice among the remaining six alternatives must therefore lean heavily on programmatic considerations.

1.5 PROGRAMMATIC EVALUATION OF ALTERNATIVES

An analysis carried out in this document examines the extent to which each of the seven alternative plans meets the seven policy objectives. A summary of this analysis follows:

Objective	Best alternatives	Worst alternatives
Stated intentions	2, 3	7
Existing opportunities	2, 3	7
Work at actual sites	No distinction	
Deliberate steps	2, 3 or 5, 6	4, 7
Early experience with TRU waste	2, 3	4, 7
Early experience with ISF	2, 5	3, 4, 6, 7
Combination of facilities	2, 4, 5, 7	3, 6

This summary suggests that alternatives 2, 3, and 5 merit the most favorable consideration among all the alternatives evaluated.

2 Background and Scope of the WIPP Alternatives

During the last two decades the disposal of radioactive waste in geologic formations has been studied through exploration, laboratory experiments, field tests, and analysis; these efforts have produced a conceptual design for a repository and have characterized one possible site. In the last 2 years, a presidentially chartered Interagency Review Group (IRG) on Nuclear Waste Management has reassessed the entire waste-management effort and has recommended a unified program. The 20 years of study and the recent recommendations have led to an analysis, presented in this environmental impact statement, of the Waste Isolation Pilot Plant (WIPP) and of alternatives to it.

This chapter summarizes the history of the waste-management program and the IRG's recent reassessment of the program; it derives major programmatic objectives from this reassessment; it defines the WIPP reference proposal, which embodies the earliest opportunity to address those objectives; and it presents programmatic alternatives to the WIPP reference proposal that are compatible with those objectives.

2.1 NUCLEAR-WASTE-MANAGEMENT POLICY

Large quantities of radioactive waste have resulted from the production of nuclear weapons as part of the U.S. defense effort. The production of electricity in commercial nuclear reactors is also generating radioactive waste. The kinds of waste considered in this document are high-level waste (HLW) and transuranic (TRU) waste. High-level waste is the residue left after reprocessing spent fuel to recover uranium and plutonium for further use; spent fuel from nuclear reactors discarded without reprocessing is also high-level waste. It is characterized by high levels of heat and penetrating radiation. Transuranic waste is any solid radioactive waste, other than high-level waste, that is contaminated with transuranic nuclides to the extent that it is not suitable for surface disposal.

2.1.1 Early History of Waste-Management Programs

In 1955, the U.S. Atomic Energy Commission (AEC) asked a committee of the National Academy of Sciences to examine the issue of permanent disposal of radioactive waste. They concluded (NAS/NRC, 1957) that "the most promising method of disposal of high-level waste at the present time seems to be in salt deposits." They recommended salt for further evaluation because of its thermal and physical properties and because its very existence for hundreds of millions of years has demonstrated its isolation from aquifers and the stability of the geologic formations in which it is located. This recommendation led the AEC to sponsor several years of research (1957-1961) at the Oak Ridge National Laboratory (ORNL) on phenomena associated with radioactive-waste disposal in salt.

In 1962, Pierce and Rich (1962) reported on salt deposits in the United States that might be suitable for the disposal of radioactive waste. The Delaware basin in eastern New Mexico was one of the areas discussed.

In 1963, the ORNL research was expanded to include a large-scale field program in which simulated waste (irradiated fuel elements), supplemented by electric heaters, was placed in salt beds for the observation of resulting phenomena. This experiment, called Project Salt Vault (Bradshaw and McClain, 1971), was conducted in an already-existing salt mine at Lyons, Kansas, from 1963 to 1967.

In June 1970, the Lyons site was tentatively selected by the AEC as a potential location for a nuclear-waste repository; the selection was conditional on satisfactory resolution of site-specific issues under study. The concept and location were conditionally endorsed by the NAS/NRC committee in November 1970. A conceptual design for a repository accommodating both high-level waste and TRU waste was completed in 1971. In 1972, however, the site was judged unacceptable for technical reasons: there were previously undiscovered drill holes nearby, and water used in nearby solution mines could not be accounted for. Accordingly, the decision was made to abandon that site.

2.1.2 The Site-Selection Process

The rejection of the Lyons site led the AEC, with the assistance of the U.S. Geological Survey, to seek sites elsewhere in the United States.

The site-selection process can be thought of as a set of information screens (Table 2-1) proceeding from general ideas to specific details, from large areas of the country to small, well-defined ones, and from surveys of the literature to measurements in the field. This information screening involves a progressively more stringent application of the site-selection criteria.

Stage 1 of this screening is one of general information gathering. Application of general desiderata at this level of knowledge leads quickly to a few regions that warrant further investigation.

Stage 2 is a careful study of the literature to narrow the remaining regions down and to identify potentially acceptable sites, from which are chosen the ones that best meet the site-selection criteria. Each candidate site thus chosen then becomes the focal point for the detailed studies required to support engineering, safety, and environmental evaluations.

Stage 3 includes extensive field studies at the candidate sites: detailed investigation of geologic structure and stratigraphy, hydrologic characteristics, and resources present; an archaeological and historic site survey; demographic and biological studies; and the operation of a meteorological station. At this stage of the screening process the site-selection criteria may be refined or added to. It is possible that these detailed studies will reveal some aspects of the sites that are less than ideal, but it is not necessary that a site be ideal with respect to all selection factors. However, a site may be rejected at this stage, and the process may back up to stage 2.

Finally, stage 4 is site analysis, including the nuclear-safety analysis and environmental impact assessment required by law. The basic question, acceptability of the candidate sites, must be answered only after taking account of the full repository system: the specific geologic environment, the

Table 2-1. Site Selection as a Screening Process

Stage	Function	Action	Decision
1	General information	Select storage media; define geographic regions where they occur; consider their characteristics in terms of tentative selection criteria	Select one (or more) regions for further study
2	Regional studies	Identify potential study areas and apply selection criteria	Select most promising study areas and candidate sites for further study
3	Site studies	Conduct detailed field studies to characterize candidate site(s) fully; determine details about how each site meets the selection criteria; determine site factors that are less than ideal	Proceed to step 4 or reject sites and select alternative candidate site or sites
4	Site analysis	Analyze site-specific characteristics and environmental impacts; determine risks of using each site	Accept or reject each site

waste form, the plant design, and potential failure modes. Analysis of the inevitable shortcomings of the sites must evaluate their influences, large or small, on the ability of the sites to isolate the waste indefinitely. If a candidate site is acceptable, the selection process is done and the site may be used immediately or held for future use; if not, the process may be started over again.

This four-stage process has been used since 1972 in the search for acceptable sites. The next section describes its application to the search that led to the WIPP reference site and to the continuing searches for sites in geologic media other than bedded salt.

2.1.3 History of Site Selection for the WIPP

Stage 1 of the process

In 1973 the Atomic Energy Commission, the Oak Ridge National Laboratory, and the U.S. Geological Survey (USGS) began seeking repository sites. As described in Section 2.1.2, the first task in stage 1 of the selection process is to choose storage media; the search in 1973 was directed primarily toward sites in salt, although shale and limestone sites were also considered (ORNL, 1972).

The tentative selection criteria (ORNL, 1973) used in the second task of stage 1, evaluating the regions where salt occurs, were as follows:

Depth of salt	100-2500 feet
Thickness of salt	At least 200 feet
Lateral extent of salt	Sufficient to protect against dissolution
Tectonics	Low historical seismicity, no salt-flow structures near
Hydrology	Minimal groundwater
Mineral potential	Minimal
Existing boreholes	Minimum number
Population density	Low
Land availability	Federal land preferable

These criteria are mostly geologic and logistic; they are primarily concerned with nuclear safety, mine safety, and ease of construction. The criterion of minimal groundwater recognizes that, as a barrier to the release of radioactivity, an inefficient hydrologic transport system is second in importance only to the salt itself. The requirements on thickness of salt, lateral extent of salt, and number of boreholes are to protect the repository from dissolution. The criterion of low population density and the preference for Federal lands minimize the potential for land-use conflicts.

During this search, criteria were added to require that there be no deep boreholes within 2 miles and that the available land area include 3 square miles and a buffer zone as well. Bedded-salt regions appeared at the time to be the most promising; however, salt domes and anticlines (upward folds) were also considered.

The USGS gathered information about 36 salt domes in the Gulf salt-dome regions (Figure 2-1). Salt domes are formed when salt flows upward, piercing overlying rocks. Where these processes are active, one might question the long-term stability of the domes, but there is reason to suspect that the ones farthest from the Gulf of Mexico are no longer growing or are growing very slowly (Bartlett et al., 1976, p. C.67). Further investigation is needed to clarify these phenomena, but salt domes remain potential alternatives for waste disposal in salt, and they are currently under evaluation in the National Waste Terminal Storage (NWTS) program for the disposal of commercial waste (Appendix B; Bechtel, 1978a).

The Paradox basin of southeastern Utah and southwestern Colorado (Figure 2-1) contains a series of northwest-trending salt-cored anticlines in which the salt reaches within 500 to 3000 feet of the surface along the northeastern edge of the basin. In the larger structures there has been some flow of salt from flanking areas into the anticlines under the influence of overburden

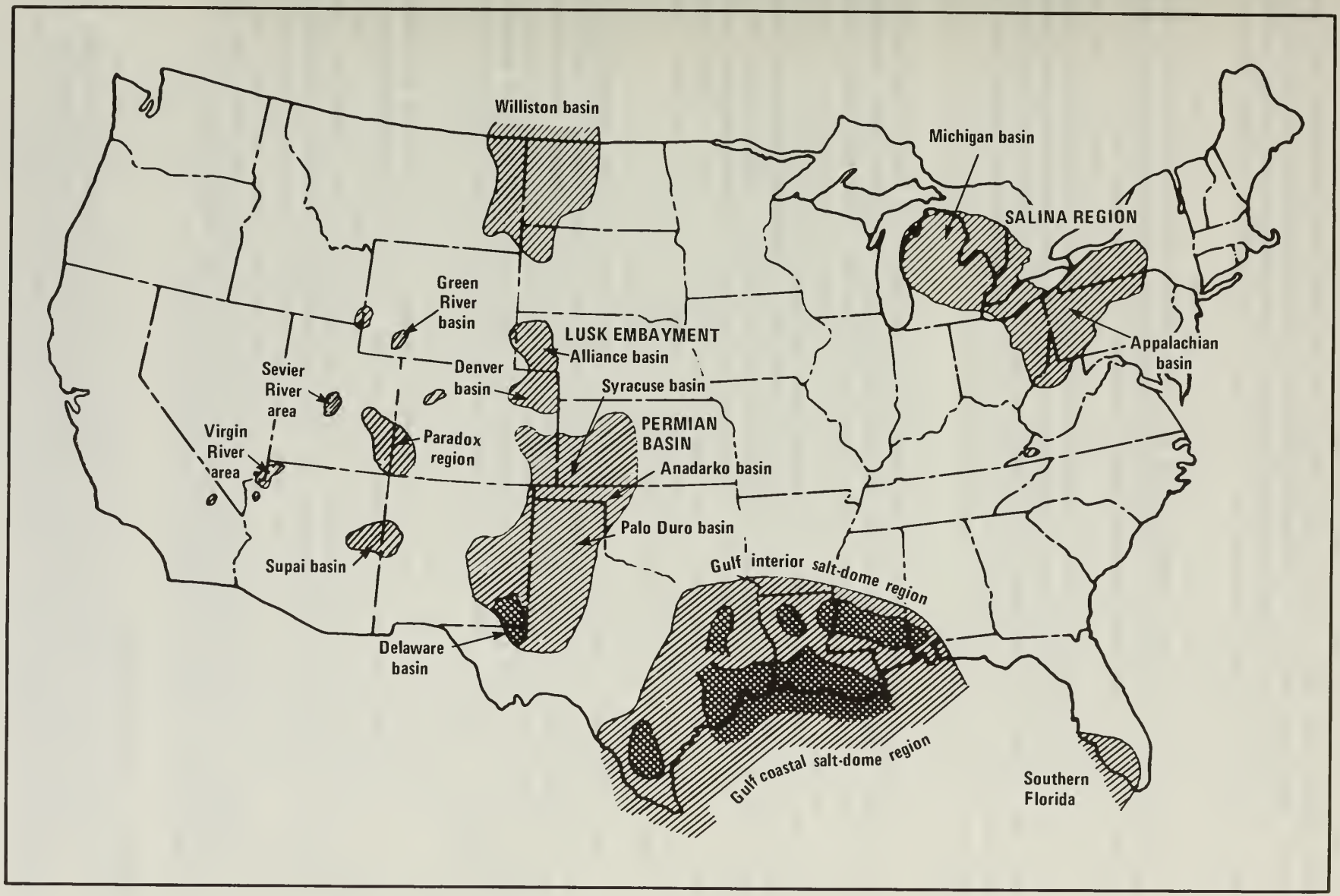

Figure 2-1. Rock-salt deposits in the United States.

pressure. Dissolution of salt from the upper surfaces of the central cores has developed a caprock of insoluble material along the crests of the salt anticlines, with the result that further dissolution is proceeding only very slowly (Bartlett et al., 1976, pp. C.97-118). Thus anticlines remain potential alternatives for waste disposal in salt, and they are currently under evaluation in the NWTS program for the disposal of commercial waste (Appendix B; Bechtel, 1978b).

Large areas in the United States are underlain with bedded salt. The USGS search looked particularly at the Supai salt basin, the Salina region, the Williston basin, and the Permian basin (Figure 2-1) (Barnes, 1974).

The Supai salt basin is in east-central Arizona on the Colorado Plateau. It is a small area of Permian evaporites underlain with limestone and overlain with the Coconino sandstone. The salt occurs in a series of beds from 50 to 400 feet thick. The Coconino is the principal aquifer of the region and is responsible for salt-dissolution collapse features in the southwest part of the basin (Mytton, 1973).

The Salina region consists of bedded-salt deposits of Late Silurian age underlying portions of New York, Pennsylvania, West Virginia, Ohio, Michigan, and southern Ontario. Strata both above and below the salt are occasionally water-bearing. However, in many areas the salt beds are overlain with massive anhydrite and dolomite units or shales that are potential hydraulic barriers. The greatest aggregate thickness of salt occurs in Michigan, where it ranges from 500 feet at the margins to 1800 feet in the center. This bedded salt is considered one of the better alternatives to the salt of southeastern New Mexico, but the area is much more densely populated, the land is more intensely used, and the hydrologic characteristics are likely to be much more complex to define and evaluate (Appendix B; NUS, 1978a).

The Williston basin is a large basin in the north-central United States and adjacent portions of Saskatchewan and Manitoba. The evaporite beds in it are deep, from 4000 to 12,000 feet below the surface, and their depth was the basic reason why the Williston basin was not considered further by ORNL and the USGS. Excavations in it would close quickly, and mining would be quite expensive. Moreover, this basin contains the richest potash deposits in North America.

The Permian basin in the western United States is a series of sedimentary basins in which rock salt and associated salts accumulated during Permian time over 200 million years ago. The region includes the western parts of Kansas, Oklahoma, and Texas and the eastern parts of Colorado and New Mexico. (The Kansas salt beds first considered are in the northern portion of the Permian basin.) Since Permian time the basin has been relatively stable tectonically, although some parts of it have been tilted and warped, have undergone periods of erosion, and have been subject to a major incursion of the sea. Subsidence or collapse of the land surface from dissolution has been common in the basin (Appendix B; Bachman and Johnson, 1973; NUS, 1978b).

Stage 2 of the process

From the bedded-salt regions surveyed in stage 1, the USGS and ORNL selected eastern New Mexico as the area in the United States best satisfying their site-selection guidelines. This area is well known geologically; it is the

part of the Permian basin with the flattest bedding at reasonable depths outside of Kansas. In some parts of the Permian basin there has been much deep drilling for oil and gas; the choice of eastern New Mexico minimized the problem of avoiding such holes.

Four locations in New Mexico were examined in more detail (Brokaw et al., 1972; Jones et al., 1973; Jones, 1974a, 1974b), and a location in the northern part of the Delaware basin was chosen for exploratory work. One of the more restrictive site-selection criteria, adopted primarily because of the Lyons experience, proved to be avoidance of drill holes penetrating through the salt within 2 miles of the repository border. This criterion caused the potential site to be shifted twice as new oil or gas wells were drilled nearby. The eventual site selected by ORNL was on the Eddy-Lea County line, about 30 miles east of Carlsbad, New Mexico.

Stage 3 of the process

Field investigations began in 1974 but were then halted as the AEC shifted emphasis to the concept of surface storage facilities, rather than mined repositories, for high-level waste.

In 1975, the successor agency to the AEC, the Energy Research and Development Administration (ERDA), restarted the program in the Delaware basin. The program was reoriented toward a mined repository for the disposal of TRU waste with a research-and-development capability for experimentation with high-level waste in salt.

The first task was to confirm the adequacy of the then-current site area. Additional drilling and geophysical investigation encountered unexpected geologic structure: rock strata were much higher than expected, beds exhibited severe distortion with dips of up to 75 degrees, sections of the upper Castile Formation (the formation below the Salado Formation, the principal salt-bearing formation) were missing, and fractured Castile anhydrite encountered at a depth of 2710 feet contained a pocket of pressurized brine. The geologic structure at this site appeared to be very unpredictable because of its nearness to a formation called the Capitan reef. The structure could have been delineated by drilling, but extensive drilling would have been contrary to the principle of minimizing the number of holes drilled into the repository. That site was given up.

In late 1975, the New Mexico portion of the Delaware basin was reexamined by the USGS and ERDA. The criteria used in looking for a new location were the following (Griswold, 1977):

1. The site should be at least 6 miles from the Capitan reef. (This criterion was added as a result of the earlier experience. It serves also to avoid any possible dissolution hazard related to the nearness of the reef.)

2. The central 3 square miles designated for the repository itself should not be in the Known Potash District, and as little as possible of the surrounding buffer zone should be in the district. (This criterion was to avoid conflict with mineral resources. As indicated in Section 7.2.7, later exploration disclosed that more such resources are present than were thought at the time.)

3. No part of the central area should be closer than 1 mile to holes drilled through the Castile Formation into underlying rocks. (This distance was reduced from the earlier 2-mile criterion as a result of analysis based on the work of Snow and Chang (1975), which indicated that dissolution by water flowing through an inadequately plugged borehole through the Salado Formation would not reach a mile in less than 250,000 years.)

4. Known oil and gas trends should be avoided. (This criterion was to avoid conflict with these resources.)

5. The site should be at least 1 mile from the nearest dissolution front. (The nearest one is the Nash Draw dissolution front. It is at the top of the Salado Formation, 1220 feet above the upper repository level; there is probably another near San Simon Sink. The rates of advance of the former front are 6 to 8 miles per million years horizontally and 500 feet per million years vertically.)

6. Bedding should be nearly flat, so far as can be determined by geophysical investigations at the surface. (This criterion is to insure mine safety and to ease construction. It also avoids the need for many holes with a consequent risk of losing repository integrity.)

7. Salt of high purity should be available at depths between 1000 and 3000 feet. (The depth requirements are to insure mine safety and to ease construction. In addition, a salt thickness of 200 feet or more is preferred in order to confine thermal and mechanical effects to the salt.)

8. State and private land use should be minimized, especially in the central area. (There is no way to avoid State land completely, because 4 square miles out of every 36 in New Mexico are State land. Avoidance of private land simplifies land acquisition and makes it unnecessary to dislocate people.)

Figure 2-2 shows some of these criteria applied to the Delaware basin. The criteria shown are the first, second, third, and fifth criteria; the rest do not lend themselves to a graphical presentation on this scale. The most restrictive criterion is the third, the one that calls for a distance of at least 1 mile from deep drill holes. Eight small areas within the basin that meet this criterion are shown numbered; areas 1 and 8 are actually parts of one very large area, but they have been split in two for this discussion. Table 2-2 applies the eight criteria to these eight areas and adds information about the distance to, and size of, the nearest town.

Three areas survived the screening based on the eight criteria, although not without questions about each of the areas. Such questions do not necessarily rule out an area; one does not insist that a site must meet every criterion. Instead, as the IRG Subgroup puts it, "most site suitability criteria will need to be rather general because the systems view dictates that the overall, cumulative effects of the geologic environment and its interaction with the waste is more important than any particular characteristics of a site" (IRG Subgroup, 1978, p. 78).

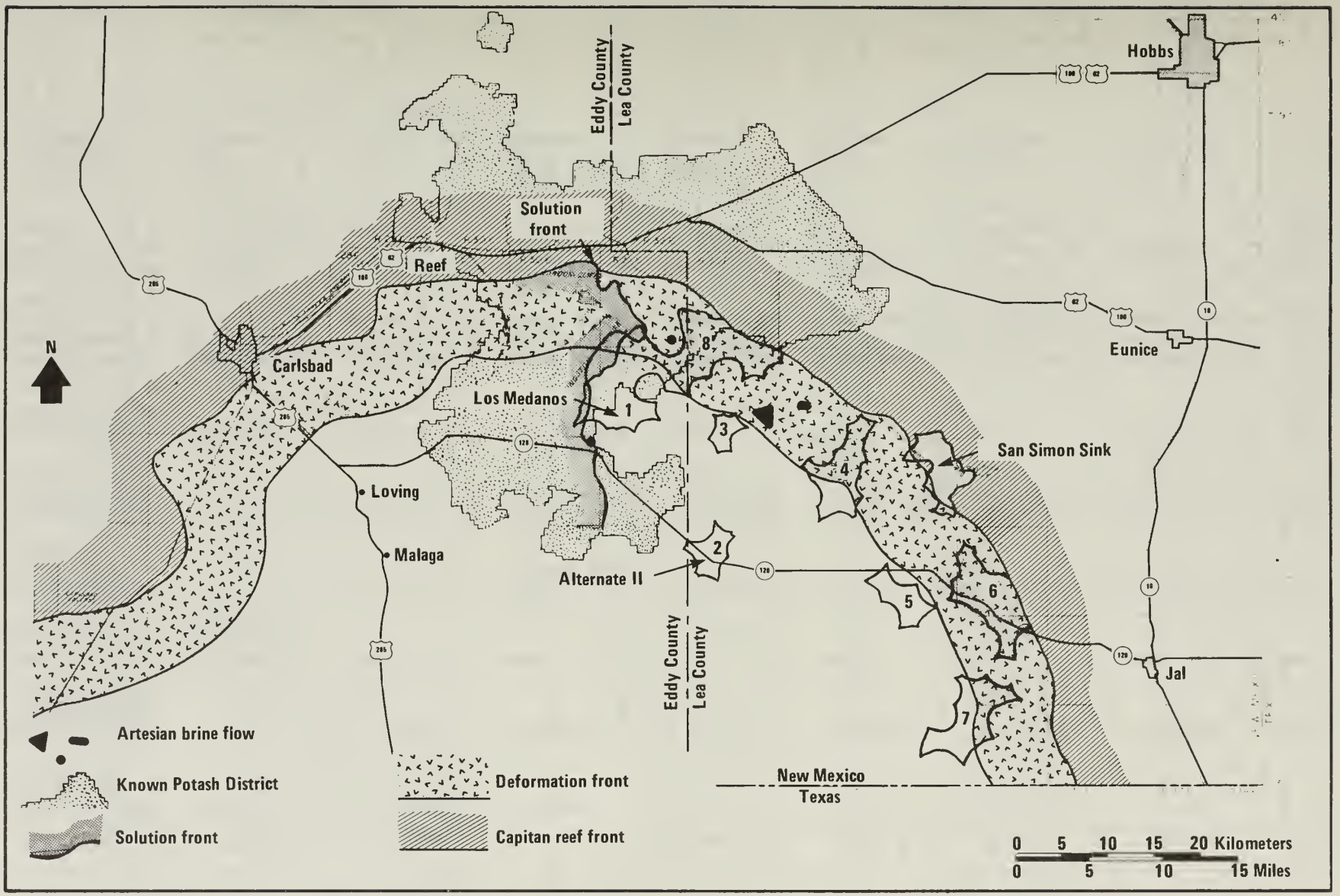

Figure 2-2. Application of the site-selection criteria to the Delaware basin.

Table 2-2. Application of Site-Selection Criteria to Eight Areas in the Delaware Basin

Criterion	Area 1	Area 2	Area 3	Area 4	Area 5	Area 6	Area 7	Area 8
1. At least 6 miles from Capitan Reef	6-10 miles	11-15 miles	5-8 miles	0-8 miles	6-8 miles	0-4 miles	2-9 miles	0-6 miles
2. Site proper not in known potash district (KPD)	[a]	No overlap	No overlap	No overlap	No overlap	No overlap	No overlap	Half of area in KPD
3. Deep drill holes at least 1 mile away	Area chosen to meet this criterion	Same	Same	Same	Same	Same	Same	Same
4. Avoid known oil and gas anticlines	[b]	Near several	Monocline near Red Tank Field	Near Cruz Field	None known near	None known near	Near Arena Roja Field	None known near
5. At least 1 mile from nearest dissolution front	[c]	Over 5 mi from Nash Draw front	Over 8 mi from Nash Draw front	Probably near San Simon Sink front	Probably near San Simon Sink front	Probably near San Simon Sink front	May be near San Simon Sink front	Over 1 mi from Nash Draw front
6. Flat bedding, less than 2° dip	Less than 1°	Less than $1/2^{o}$	Less than $1/2^{o}$	About 2°	Flat	Over 2°	Varies, 0-1.2^{o}	Over 2°, and drilling proved unacceptable
7. Good salt 200 ft thick between 1000- and 3000-ft depths	Salado 860-2836 ft; infra-Cowden 290 ft	Salado 1500-3400 ft, infra-Cowden missing	Salado 1350-3350 ft, infra-Cowden 225 ft	Salado 1850-3850 ft, infra-Cowden 200-300 ft	Salado 2100-4100 ft, infra-Cowden missing	Salado 1900-3900 ft, infra-Cowden thin (100-150 ft)	Salado 1800-3800 ft, infra-Cowden missing	Salado 800-2900 ft, folded infra-Cowden 300 ft
8. Minimize use of State and private land	Area chosen has no private land, 2.7 sq mi state	No private land, small amount state land	No private land, small amount state land	Mostly state land, 0.4 sq mi private	Over half private land	About half private land, some state land	Criterion not examined	Some private land, several square miles state land
9. Nearest town Population Distance	Loving 1100 18 miles	Malaga 300 22 miles	Malaga 300 24 miles	Eunice 2500 24 miles	Jal 2700 12 miles	Jal 2700 10 miles	Jal 2700 12 miles	Loving 1100 23 miles
Criteria in conflict	2? 4? 5?	4?, 7	1?, 4?	1, 4, 5?, 6, 8	5?, 7, 8	1, 5?, 6, 7, 8	1, 4, 5?, 7	1, 2?, 6, 8

[a]Area chosen had part of buffer zone in KPD, rest free.
[b]Synclinal area next to a producing gas well.
[c]Nash Draw front overlaps part of area.

Of the five areas that did not survive the screening, four were too close to the reef front; one, area 8, was largely within the Known Potash District; two were near known oil fields; four were probably too near the dissolution front that must be around San Simon Sink; three did not have flat enough bedding; three were nearly too deep or too lacking in infra-Cowden salt or both; and four would involve private land. (Infra-Cowden salt lies near the base of the Salado Formation; it is the purest salt of the formation and the salt proposed for the lower mining level in the WIPP reference repository. It is still not clear, however, how important the salt-purity criterion is.)

Conditions peculiar to area 3 eliminated it from further consideration. It was the smallest of the surviving areas. It was almost, but not quite, excluded by criterion 1. Most importantly, it is near three deep holes (shown by the black triangle in Figure 2-2) that had been drilled while exploring for oil and gas. They were described as having had brine flows that were in turn described as "strong," 20,000 barrels per day, and 36,000 barrels per day. By comparison, the brine pocket intercepted by drill hole ERDA-6 flowed at the rate of only 660 barrels per day. These three holes would be in the buffer zone if area 3 were to be selected.

Thus two areas remained. Between the two, area 1 was then and remains today preferred over area 2 because as a whole the problems with area 2 are more serious than those with area 1.

In area 2, the salt is deeper than in area 1, and mining and mine safety would be harder to insure. There is no infra-Cowden salt in area 2. Area 2 is next to two shallow oil fields where water flooding for secondary recovery may eventually be used. A seismic center on the Central Basin platform 25 to 65 miles to the east is believed to be the result of such flooding (Section 7.2.6), and it would be well to avoid the possibility, although the Delaware basin is quite stable tectonically compared to the Central Basin platform and hence little likely to be subject to induced seismic activity.

In area 1, on the other hand, the remaining questions either do not affect repository integrity or are found to be nonproblems.

Area 1 met the second criterion imperfectly, the one concerned with interference with possible future potash mining. When the sites were being screened it appeared that a site (the present reference site) could be chosen in which the central area would be outside the Known Potash District and that thus the site would be minimally in interference with potash minerals. As it turns out, information from potash exploratory holes drilled since then by the DOE has caused an enlargement of the Known Potash District to include most of the present reference site. Control zone I remains largely free of indicated potash mineralization. Thus area 1 remains in conflict with the second criterion. While this criterion does not affect repository integrity per se, the existence of mineral deposits might attract drilling after control over the site has been lost.

In determining how well area 1 satisfies the fourth criterion, which is concerned with avoiding oil and gas resources, subsequent analysis has shown that there are no oil reserves under the reference site. There are some gas reserves. These are a small fraction (0.02%) of the nation's reserves, and at least some of this gas can be withdrawn from outside the site or from within control zone IV.

Area 1 satisfies the fifth criterion, the one concerned with the nearness of the Nash Draw dissolution front. There are 1200 feet of salt over the upper repository level, which, given a vertical dissolution rate of 500 feet per million years, provide an isolation time of 2.4 million years.

Thus a new site was identified in the area called Los Medanos, about 6 miles southwest of the first site. This is the present WIPP reference site. Since 1975 the DOE has sponsored continuing and intensive studies there; the results to date are reported in the Geological Characterization Report (Powers et al., 1978) and summarized in Chapter 7 of this document. These studies constituted a principal part of the stage 4 analysis. This environmental impact statement is also a major part of stage 4.

In 1978, a DOE task force suggested (DOE, 1978a) that the WIPP include a demonstration of the disposal of spent fuel from nuclear reactors; under their recommendation, up to 1000 spent-fuel assemblies would be emplaced retrievably in a specially designed part of the WIPP mine. The site-selection criteria remained unchanged after this addition of the high-level waste in the form of spent fuel to the mission. These criteria, originally established for high-level waste, were retained for TRU waste because they were needed to take account of potential long-term problems with TRU nuclides. The primary difference between TRU waste and spent fuel is in the heat delivered to the repository. Over the long term, thousands of years, the fission products in spent fuel decay, leaving the radioactive actinides. These actinides from the spent fuel are nearly the same as those remaining in the TRU waste, and their impacts and interactions inside the repository and the biosphere are similar. In the short term, up to 1000 years, the spent fuel delivers heat to the repository; TRU waste, which is a negligible heat generator, does not. Limitations on heat loading can reduce the near-term consequences of this heat; retrievable emplacement can allow them to be mitigated if monitoring, further research, or analysis of these consequences shows that corrective action is needed.

2.1.4 The Continuing Site-Characterization Program

Along with the investigations in the Delaware basin, ERDA continued its site-characterization program for mined repositories for the disposal of commercially generated high-level waste. This National Waste Terminal Storage (NWTS) program is considering a wide variety of media in diverse regions of the country in addition to bedded salt (Appendices A and B).

The other rocks being studied are crystalline rocks (basalt and granite), argillaceous rocks (shale), and tuff. Rock salt has received most of the attention in waste-disposal studies over the past two decades; hence a great deal more information is known on the properties of salt than on the properties of the other rocks. None of the other rocks is as soluble as salt. Shale is somewhat plastic, but not so plastic as salt. Typically, salt is free of flowing groundwater whereas basalts, granites, and tuffs contain such water; although shale often contains water, it is often nearly impermeable. All the other rocks have a much greater sorptive capacity and a smaller thermal conductivity than salt (Appendix A).

No intrinsic environmental or safety-related problems have been identified that would clearly preclude the use of any of these media for a repository. On the contrary, it appears that any problems associated with these media could be solved by judicious site selection, by engineering design using state-of-the-art technology, or by both methods. Nevertheless there are more unanswered questions about the use of these other rocks than about the use of salt.

The WIPP and NWTS programs have identified general locations of potential interest for repositories. Some locations are still being investigated further, and some have been rejected; while some areas have been studied no further because others appear to have greater potential, they have not been rejected--they remain as potential sites in the NWTS program.

Although the Los Medanos reference site is the only location to date to have reached the stage 4 degree of characterization, the NWTS program will eventually take alternative locations to that stage. The implications of this progress, in terms of alternatives to the reference case, are developed in this chapter and evaluated in Chapters 3 and 4.

2.1.5 The IRG Process--A Current Reassessment of the Waste-Management Program

President Carter called for a review of the waste-management program in his April 1977 National Energy Plan. In response to this request, the DOE established an internal task force and published a draft report in March 1978, containing significant criticisms, findings, and recommendations (DOE, 1978a). The President then created a formal Interagency Review Group on Nuclear Waste Management and instructed it to make policy and program recommendations to him, using the draft DOE task force report as one input. This group, chaired by the DOE, comprised representatives of 14 agencies. It developed a draft report to the President that was published for public comment in October 1978 (IRG, 1978). Following the review of public comment, the Interagency Review Group has published a revised report (IRG, 1979) and is now preparing a Decision Paper for the President, who will determine an administration position on the issues identified by the Interagency Review Group.

At the outset, the DOE task force found that a majority of independent technical experts have concluded that high-level waste can be safely disposed of in geologic media, although validation of the specific technical choices will be an important element of the licensing process. An important recommendation was that consideration be given to an early demonstration of the geologic disposal of up to 1000 spent-fuel assemblies in the WIPP or in another suitable location; this demonstration, designed for conservative levels of heat generation, would allow research-and-development measurements to be made. The task force recommended that both the TRU-waste disposal and the spent-fuel demonstration be subject to licensing by the Nuclear Regulatory Commission (NRC).

The task force rejected the idea that the WIPP be considered as a potential repository for high-level waste from the defense program, recommending

that the WIPP be dedicated to TRU-waste disposal. The task force concluded its discussion of the WIPP (DOE, 1978a, p. 18) as follows:

> Thus, in summary, WIPP would be used for R&D in salt and ultimate disposal of TRU wastes as originally proposed. The Task Force recommends that this mission be supplemented by a demonstration of spent-fuel disposal. These activities should be licensed. Any change in scope or character from this approach will be subject to a licensing revision process involving the opportunity for significant state and public participation.

Subsequently, the Interagency Review Group consulted extensively with the scientific and technical community, including independent geologic and environmental experts. The major technical findings of this activity (IRG, 1979, p. 42) are presented in full below.

> Present scientific and technological knowledge is adequate to identify potential repository sites for further investigation. No scientific or technical reason is known that would prevent identifying a site that is suitable for a repository provided that the systems view is utilized rigorously to evaluate the suitability of sites and designs, and in minimizing the influence of future human activities. A suitable site is one at which a repository would meet predetermined criteria and which would provide a high degree of assurance that radioactive waste can be successfully isolated from the biosphere for periods of thousands of years. For periods beyond a few thousand years, our capability to assess the performance of the repository diminishes and the degree of assurance is therefore reduced. The feasibility of safely disposing of high-level waste in mined repositories can only be assessed on the basis of specific investigations at and determinations of suitability of particular sites. Information obtained at each successive step of site selection and repository development will permit reevaluation of risks, uncertainties, and the ability of the site and repository to meet regulatory standards. Such reevaluations would lead either to abandonment of the site or a decision to proceed to the next step. Reliance on conservative engineering practices and multiple independent barriers can reduce some risks and compensate for some uncertainties. However, even at the time of decommissioning some uncertainty about repository performance will still exist. Thus, in addition to technical evaluation, a societal judgment that considers the level of risk and the associated uncertainty will be necessary.

The Interagency Review Group raised an important issue about TRU-waste disposal: should a dedicated TRU-waste repository be built if an opportunity exists to do so, or should TRU-waste disposal await the availability of HLW repositories and take place there? The IRG report states (IRG, 1979, p. 73) that "the IRG still considers that proceeding with a dedicated TRU repository, if an opportunity is available, is consistent with a conservative and stepwise approach."

It should be noted, however, that the Interagency Review Group approached this question generically, as an appropriate interim strategic-planning basis until the environmental-review provisions of the National Environmental Policy Act (NEPA) have been carried out. This environmental impact statement is the NEPA document in which the full environmental considerations of such an approach are analyzed so that the DOE can reach a decision.

The Interagency Review Group recommended a detailed interim strategic-planning basis for the HLW program, again pending NEPA review. The generic environmental impact statement (GEIS) on the Management of Commercially Generated Radioactive Waste (DOE, 1979a), issued in draft form in March 1979, is intended to represent the formal NEPA documentation for the HLW strategy.

The Interagency Review Group defines an intermediate-scale facility (ISF) as a licensed facility, in which hundreds, perhaps as many as 1000, spent-fuel assemblies are emplaced retrievably but with the intention of leaving them there permanently for disposal. Such a facility would be a deliberate, technically conservative step toward the permanent disposal of nuclear waste; it would provide technical data and help to develop the institutional arrangements that will be needed for full-scale waste disposal.

The Interagency Review Group found that (IRG, 1979, p. 63)

> An ISF is not an essential component of a program leading to a full-scale repository. Nonetheless, if an appropriate opportunity to build an ISF on a schedule significantly prior to the opening of the first full-scale, high-level waste repository were to exist, the opportunity should be taken.

The members of the Interagency Review Group have not agreed on the timing and procedures for siting an ISF or on the matter of colocating an ISF with a dedicated TRU-waste facility. Additional elaboration of the IRG's views is furnished in Appendix C.

2.2 NEAR-TERM WASTE-MANAGEMENT OBJECTIVES

The Interagency Review Group has stated (1979, p. 15) that the primary objective of waste-management planning and implementation is that

> Existing and future nuclear waste from military and civilian activities (including discarded spent fuel from the once-through nuclear fuel cycle) should be isolated from the biosphere and pose no significant threat to public health and safety.

This document analyzes potential near-term steps toward the achievement of that longer-term objective. This section discusses three near-term objectives: meeting stated intentions for TRU-waste disposal; using existing opportunities for progress; and providing technical, institutional, and operational benefits to the HLW-disposal program.

2.2.1 Meeting Stated Intentions

This objective would fulfill the U.S. Government's intentions, expressed to the State of Idaho, regarding TRU-waste disposal. In 1970, the AEC noted that it viewed shipment of TRU waste from Idaho to a Federal repository as a high-priority requirement, hoping then to start by the end of the decade (letter, G. T. Seaborg to Senator Frank Church; see DOE, 1979b, Appendix A). That plan was made when the AEC was working to establish a demonstration repository in salt at Lyons, Kansas, to be available in 1976. However, as noted in Section 2.1.1, site-specific safety questions arose at the Lyons site, and the project was abandoned in mid-1972. The desire to dispose of the waste permanently remains, however, and statements to this effect have been reiterated as late as March 2, 1978 (DOE, 1979b, Appendix A), although shipments will be delayed until 1986 or later.

2.2.2 Using Existing Opportunities

This objective takes advantage of the availability of an opportunity to proceed, as discussed by the DOE task force report (DOE, 1978a, p. 13) and the IRG report (1979, pp. 69ff).

According to these reports, proceeding now is appropriate and possible for four basic reasons summarized below:

1. There are sufficient quantities of TRU waste to warrant the construction of a single, mined repository dedicated to their disposal. This waste has been generated in defense programs. Transuranic waste will also be generated in the decontamination and decommissioning of both defense and civilian facilities.

2. To obtain the advantages of using a TRU-waste repository as a deliberate, conservative step toward HLW disposal, it is appropriate to proceed now. Because repositories for both defense and civilian HLW are expected to be available in the future and because they can also be used for TRU-waste disposal, it is unlikely that there will be another opportunity to build a repository dedicated only to TRU waste.

3. A conceptual plant design (WIPP) currently exists, and a site (Los Medanos) has been investigated; it is therefore possible to consider proceeding now with a repository specifically dedicated to TRU-waste disposal.

4. According to the IRG recommendations, the next step would be to ask the NRC for a construction permit for the facility; the question of final site suitability would then be resolved through the licensing process. Docketing of the case with the NRC would represent a view that the DOE site-characterization activities have supported the suitability of the site for a repository, as far as they have proceeded. Docketing is an appropriate step because it would permit more-detailed site examinations (including the sinking of a large central shaft and excavations at the repository horizon) to proceed in accordance with the requirements of the NRC. However, the current Congressional authorization for WIPP site characterization and design does not

include provisions for licensing; this matter would have to be resolved in order to be consistent with the IRG recommendations to the President.

2.2.3 Benefiting the HLW-Disposal Program

This objective, which may be the most significant, provides near-term technical, institutional, and operational benefits to the HLW-disposal program, as recognized by the Interagency Review Group:

1. Near-term programs should advance the technology for mined repositories. Generic laboratory work, while useful, is no longer an adequate basis for advancing the program; characterization of actual sites and experience at them is now necessary.

2. Except for the quantities of wastes, the safety considerations involved in the disposal of TRU waste are similar to those in HLW disposal: after decay of its fission products, high-level waste essentially becomes TRU waste in the very long term, after a few centuries. (On the other hand, TRU-waste disposal is operationally simpler; the waste does not generate enough heat to affect its interactions with the salt.) Much of the experience with TRU-waste disposal is directly applicable to future HLW-disposal activities, thereby providing the HLW-disposal program with experience in designing, analyzing, and operating repositories and in obtaining licenses from the NRC and other regulatory bodies.

3. Near-term TRU-waste disposal would be consistent with the desired approach of proceeding by deliberate and technically conservative steps toward final methods for waste management.

4. An ISF, licensed and limited in size, would provide the HLW-disposal program with further, independent experience in designing, analyzing, and operating repositories and in obtaining licenses from the NRC and other regulatory bodies. Colocation of an ISF at a dedicated TRU-waste repository would reduce costs below those of an independent ISF not intended as the site of a full-scale repository. Furthermore, it would be useful to have the ISF near the research-and-development work carried on in the repository.

2.2.4 Summary of Near-Term Objectives

In summary, the near-term policy objectives for waste management may be stated as follows:

1. To meet stated U.S. Government intentions for early removal of the TRU waste stored at the Idaho National Engineering Laboratory.

2. To use existing opportunities, if they are adequate and acceptable, to advance waste-management technology and to dispose of existing wastes.

3. To emphasize work at potential sites that may realistically be considered for waste disposal.

4. To proceed by deliberate steps in a technically conservative manner.

5. To build a licensed full-scale TRU-waste repository in advance of HLW repositories, thus gaining experience in designing, analyzing, and operating repositories and in obtaining approval from the NRC and other regulatory bodies.

6. To build a licensed intermediate-scale facility for the disposal of spent fuel from reactors in advance of HLW repositories, thus gaining further experience in designing, analyzing, and operating repositories and in obtaining approval from the NRC and other regulatory bodies.

7. To combine compatible facilities, where suitable, in order to avoid unnecessary costs and to assist in integrating the research-and-development programs.

2.3 THE WIPP REFERENCE CASE

2.3.1 Intent of the Reference Case

The WIPP reference case, defined in this EIS, is intended to achieve the simultaneous but potentially conflicting objectives of Section 2.2.4 as thoroughly and quickly as possible. There are questions, of course, as to whether this intent is actually achieved by the reference case. In Section 2.4, alternatives to the reference case are derived. They and the reference case are evaluated with respect to their environmental impacts in Chapter 3 and with respect to the seven policy objectives in Chapter 4.

2.3.2 Description of the Reference Case

The reference case consists of

1. A licensed, full-scale repository for the permanent disposal of TRU waste. It will receive this waste from the Idaho National Engineering Laboratory (INEL). The initial underground excavation will create a 100-acre area that can hold all the TRU waste now stored at the INEL as well as the waste expected there through 1990; future expansion of the repository can provide an area of 2000 acres for the disposal of TRU waste from other sites. All the TRU waste to be received at the WIPP will have been produced in the U.S. defense program. The waste will be emplaced in such a manner that it can be retrieved during a 20-year period if it becomes necessary to do so.

2. A 20-acre underground area for research and development. There experiments performed with all types of nuclear waste will answer technical questions about the disposal of waste, particularly high-level waste, in salt. All the waste used in these studies will be removed when the experiments are over.

3. A 20-acre underground area for the permanent disposal of spent-fuel assemblies removed from nuclear reactors. Called an "intermediate-scale facility (ISF)" by the Interagency Review Group, this part of the WIPP will receive as many as 1000 assemblies emplaced in such a manner that they can be retrieved for 10 years if necessary, but without the expectation of doing so.

Under the reference proposal, these three parts of the WIPP would all be combined at the reference site in Eddy County, New Mexico. The plans would be submitted to the licensing authorities for further consideration after completion of the material required by the NRC.

The WIPP reference site (at Los Medanos) is in southeastern New Mexico, about 25 miles east of Carlsbad. The plant would require the withdrawal of 17,200 acres of Federal land, the acquisition of 1760 acres of State land, and the cancellation of existing lease rights on both parcels of land. Another 590 acres would be required for rights-of-way for roads, a railroad, an electrical-power line, and a water line.

At the site railcars and trucks would be unloaded within a waste-handling building, where the waste would be prepared for movement underground. Each of four shafts would reach the two storage and disposal levels underground. The upper level, 2100 feet below the surface, would be used for the disposal of contact-handled (CH) TRU waste. The lower level, 2700 feet underground, would be used for the disposal of remotely handled (RH) TRU waste, for the emplacement of spent fuel, and for experiments with high-level waste. Both levels would be in the Salado Formation, a thick layer of bedded salt that extends from 860 to 2836 feet below the surface at the center of the site. More detailed information on the reference site is in Chapter 7 and Appendix D, which also discusses its compatibility with site-selection criteria.

In the reference design, the area set aside for potential underground storage operations would be about 2000 acres; the remaining acreage would provide a 2-mile-wide buffer zone around the underground operations area. The initial excavation at the upper (CH) level would provide about 100 acres for waste disposal. The lower mine level would have three separate areas of 10 to 20 acres each for the storage of remotely handled TRU waste, for the spent-fuel demonstration, and for high-level-waste experimentation. Service areas would take up additional acreage on both levels.

Operating at three shifts per day, the WIPP reference design could handle in any given year 1.2 million cubic feet of contact-handled TRU waste, 10,000 cubic feet of remotely handled TRU waste, 350 canisters of spent-fuel assemblies, and 100 canisters of high-level waste for experiments. Chapter 8 presents a detailed description of the reference repository and its operation.

It is estimated that the construction of the WIPP would cost $225 million (1978 dollars) spread over 4 years and about $36 million a year to operate. In addition, engineering, construction management, and technical support would cost $205 million. The construction work force would number about 800 people on the average; peak employment would be near 1400. The operational staff would number about 350.

2.3.3 Waste To Be Disposed of or Studied in the Reference Repository

Transuranic (TRU) waste

The U.S. defense program has already generated large quantities of contact-handled TRU waste, which requires no shielding, and remotely handled TRU waste, which requires shielding to protect workers who handle it. The acronym TRU stands for "transuranic"; transuranic waste is any solid radioactive waste, other than high-level waste, that is contaminated with nuclides heavier than uranium to the extent that it is not suitable for surface disposal. It results from almost every industrial process involving transuranic materials, but predominantly from the fabrication of plutonium to produce nuclear weapons. It would be produced in spent-fuel reprocessing and mixed-oxide-fuel fabrication for recycle to nuclear reactors; these processes, however, are not currently in commercial use in the United States.

Transuranic waste exists in a wide variety of physical forms, ranging from unprocessed general trash (absorbent papers, protective clothing, plastics, rubber, wood, ion-exchange resins, sludges, etc.) to decommissioned tools and glove boxes.

The major producers of defense TRU waste have been the Rocky Flats Plant near Denver, the Hanford complex of facilities near Richland, Washington, and the Los Alamos Scientific Laboratory in northern New Mexico. Smaller producers include the Mound Laboratory near Miamisburg, Ohio, the Savannah River Plant near Aiken, South Carolina, the Argonne National Laboratory near Chicago, the Oak Ridge National Laboratory in Tennessee, and the Lawrence Livermore Laboratory in Livermore, California. Most of this waste has been stored at the Idaho National Engineering Laboratory near Idaho Falls and at Hanford. Smaller inventories are stored at the Pantex Works at Amarillo, Texas, and at the Nevada Test Site.

The radionuclide content of TRU waste varies widely. Weapons-oriented plants like Rocky Flats produce waste in which plutonium-239 is the dominant TRU nuclide; waste from the Mound Laboratory is high in plutonium-238; and some waste from the Oak Ridge National Laboratory contains curium-244. On a volume basis, weapons waste is by far the most important component of the total TRU-waste inventory; the Rocky Flats Plant alone produces 40% of all DOE TRU waste. For this reason, Rocky Flats waste is taken in this document as representative of all DOE contact-handled TRU waste. The characteristics of such TRU waste are described in Appendix E (Tables E-1 and E-2) and Chapter 5.

There are virtually no fission products in defense contact-handled TRU waste, and its heat output is essentially zero.

Before 1970, waste containing TRU nuclides was not segregated from other waste contaminated with low levels of radioactivity. Therefore, a large volume of material now considered contact-handled TRU waste was buried in a manner similar to conventional sanitary-landfill operations, with additional handling precautions appropriate for radioactive materials. The waste was placed in open unlined trenches and then covered with several feet of earth. At the time of its burial, this waste was not intended to be retrieved.

In 1970, the AEC adopted a policy requiring that waste containing TRU nuclides producing in excess of 10 nanocuries of alpha activity per gram be

packaged and stored separately from other radioactive waste. This waste is now stored in such a way that it "can be readily retrieved in an intact, contamination-free condition for 10 years" (DOE Manual, Chapter 0511).

Remotely handled TRU waste has always been handled separately. Much of it has been put into 1- to 2-foot-diameter pipes placed vertically in the ground, with a shielding plug at the top of each pipe (Bartlett et al., 1976, Chapter 20).

At the end of 1977, the accumulated volume of TRU waste amounted to 11 million cubic feet of material, only 1.6 million cubic feet of which is readily retrievable. By the end of 1986, this volume is projected to become 13 million cubic feet, including 3.7 million cubic feet retrievably stored (Table 2-3). The estimated quantity of transuranic nuclides stored at the various DOE sites at the end of 1977 is presented in Table 2-4. About 30,000 cubic feet of remotely handled TRU waste from defense programs is now in storage; this volume is expected to grow to about 89,000 cubic feet by 1986.

Table 2-3. TRU Waste at DOE Storage Sites[a]

	Volume (thousands of cubic feet)					
	Buried		CH waste--stored		RH waste--stored	
Site[b]	10/1/77	10/1/86	10/1/77	10/1/86	10/1/77	10/1/86
LASL	580	580	54	249	0	9
Pantex	1	1	0	0	0	0
ORNL	215	222	10	32	27	52
Hanford	5483	5483	247	855	3	8
INEL	2102	2102[c]	1202	2376	0+	20
NTS	0	0	6	39	0	0
SRP	1085	1085	56	109	0	0
TOTAL	9466	9473	1575	3664	30	89

[a]Data from Dieckhoner (1978 and private communication, 1978). See also Appendix E of this document.

[b]Key: LASL, Los Alamos Scientific Laboratory, New Mexico; Pantex, Pantex Works, Amarillo, Texas; ORNL, Oak Ridge National Laboratory, Tennessee; Hanford, Hanford Reservation, Richland, Washington; INEL, Idaho National Engineering Laboratory; NTS, Nevada Test Site; SRP, Savannah River Plant, South Carolina.

[c]It is estimated that experimental retrieval programs will reduce this volume to 2 million cubic feet by 1985. However, if all of INEL's buried TRU waste is retrieved for shipment to a Federal repository, the total volume recovered will be 6.25 million cubic feet, including 3.75 million cubic feet of contaminated soil and 500,000 cubic feet of beta- and gamma-emitting waste that is intermixed with TRU waste. If this waste is treated by slagging-pyrolysis incineration, the total volume of waste shipped to the repository will be on the order of 3 million cubic feet (the overall volume-reduction ratio in the incineration process is estimated to be 2:1).

Table 2-4. Transuranic Content of DOE TRU Waste
(Estimates as of October 1, 1977)[a]

Site[b]	Buried waste (kg of TRU)	Stored waste (kg of TRU)
LASL	13	27
Pantex	0	0
ORNL	13	17
Hanford	365	78
INEL	361	273
NTS	0+	3
SRP	7	52
TOTAL	759	450

[a]Data from Dieckhoner (1977).
[b]See Table 2-3 for key to abbreviations.

The rate at which contact-handled TRU waste is produced is about 0.25 million cubic feet per year (DOE, 1978a, pp. 43, 121). The WIPP reference repository is designed to handle 1.2 million cubic feet of waste per year. Thus, if the WIPP were to start accepting waste in 1986, the easily retrieved waste could, in theory, be placed there over a 4-year time period (by 1990), although the actual time required to receive all this would probably be longer.

In addition, the WIPP reference repository has the capacity to receive some TRU waste from the dismantling and decontamination of obsolete and no-longer-needed weapons-production facilities such as the Hanford plutonium reactors. Estimates of the volume of such waste range from 5 to 95 million cubic feet, depending on the amount of contaminated soil that must accompany the waste (DOE, 1978a, p. 87). If the latter figure is correct, only part of it could be emplaced in the reference repository. (The transportation impact analyses later in this document, however, do not assume that any of this dismantling-and-decommissioning waste is sent to the WIPP.)

The reference repository is intended for the disposition of only that amount of readily retrievable waste expected to be stored at the INEL through 1990. This waste includes the 2.4 million cubic feet shown in Table 2-3 for 1986 plus an additional two-thirds of the 0.25 million cubic feet generated annually, for a total of about 3 million cubic feet. Some 100 acres of repository space will be more than adequate for this purpose.

Although the mission of the reference repository is now limited to this subset of the total TRU-waste inventory, the environmental analyses contained in Chapter 9 and summarized in Chapter 3 assume that the complete repository volume of 2000 acres is used for TRU-waste disposal, thus insuring that the reference repository would not limited by an inability to receive and dispose of additional quantities of TRU waste. Any decision to do so, however, would require further environmental review (and license amendment) at the time.

Further environmental review is also required for another decision: should the TRU waste now buried at DOE sites be exhumed, presenting near-term risks to personnel, so as to improve its long-term disposal. These reviews are to be completed by about 1982, as recommended by the IRG (1979, p. 76).

Spent fuel for the ISF

Reactor fuel consists of small uranium dioxide pellets stacked in stainless-steel or zirconium-alloy tubes. These tubes, called fuel pins or fuel rods, are assembled into bundles called fuel-element assemblies. During operation of the reactor, radioactive waste is produced in this fuel.

Approximately one-third of the fuel in a reactor is replaced each year. In a typical 1000-MWe reactor, this amounts to about 64 fuel assemblies, that is, 25 metric tons of uranium (MTU) occupying a volume of about 330 cubic feet. Spent-fuel assemblies taken from reactors are presently stored at each operating nuclear-power plant; the present inventory of this spent fuel is about 2300 MTU. By the end of the century, this inventory could grow to about 100,000 MTU (DOE, 1978b).

Because storage space at commercial nuclear-power plants is limited, storage away from reactor sites is being considered. The U.S. Government is proposing to provide some of this away-from-reactor (AFR) storage space. Under a policy announced on October 18, 1977, the Government proposes to accept and take title to spent nuclear fuel from utilities following payment to the Government of a storage fee. In addition, it may be possible to ship the spent-fuel assemblies to privately owned independent spent-fuel-storage (SFS) water basins. Three private SFS basins now exist. They are the General Electric (GE) Morris plant in Illinois, the Nuclear Fuel Services (NFS) West Valley plant in upstate New York, and the Allied-General Nuclear Services (AGNS) Barnwell plant in South Carolina.

For purposes of analysis, this environmental impact statement assumes that the spent fuel for the ISF at the WIPP will be acquired and transported from the storage basins at Morris, Illinois.

Plans for the ISF (Section 8.10) are to dispose of 10-year-old (i.e., 10 years since discharge from the reactor) spent-fuel assemblies from a pressurized-water reactor (PWR). The characteristics of 10-year-old PWR fuel are summarized in Table E-5 of Appendix E. The PWR assemblies have been selected because of their dimensional compatibility with the WIPP transfer equipment for remotely handled waste. They will be encapsulated intact in individual canisters.

Nature of waste for experimental program

The experimental program described in Section 8.9 will be designed to answer technical questions about the disposal of spent fuel and other high-level waste in bedded salt. This research-and-development program will provide an in-situ laboratory that can study, in addition to other phenomena, the questions that may arise concerning the disposal of spent fuel in the ISF. The focus of the program is on spent fuel and other commercial high-level waste rather than on TRU waste and defense high-level waste; the former are more radioactive and generate more heat than the latter and thus have more potential for undesired consequences.

In the experimental area, it will be possible to accelerate the interactions between the high-level waste and the salt and to experiment with canister materials, overpack or backfill materials, and other multiple-barrier techniques. The experimental program can produce information on means of

protecting the spent-fuel canisters from brine attack for long periods of time, on the products of spent-fuel interactions with salt, and on various concepts for immobilizing any leached radionuclides within or near the original waste-emplacement locations.

The experiments will use waste that produces high levels of heat and gamma radiation--spent power-reactor fuel and solidified high-level waste. (The spent fuel used in the experimental program will be in addition to that used in the ISF.) In the interest of accelerating the interactions, some of the waste will be emplaced without a surrounding container; some will be ground into small particles before being emplaced. All the waste used in experiments will eventually be recovered and removed from the WIPP.

The source of the waste to be used in these experiments is not as yet defined. Spent fuel is available from many sources; each reactor and spent-fuel storage facility is a potential source. On the other hand, solidified high-level waste is not readily available. (Except for some laboratory-scale batches, no commercial high-level waste has been produced in this country since 1971, and little defense high-level waste has been produced. Furthermore, the high-level waste in storage has decayed to much lower radiation levels than it had when originally produced.) There will be a need for commercial high-level waste in the WIPP experiments because it produces higher outputs of heat and radiation than does defense high-level waste. The experiments are intended to stress the salt environment severely enough to simulate adverse conditions that, in concept, might appear in a future repository for high-level waste. They are also intended to cover the possibility that reprocessing of commercial spent fuel may resume, requiring disposal of solidified high-level waste; for this purpose only actual commercial waste will be adequate because the chemical interactions between defense waste and its surroundings in a repository will be significantly smaller.

If solidified commercial high-level waste is not available, the experiment program may have to use fresh defense high-level waste, which produces heat and radiation at levels roughly 10 times lower than those of commercial high-level waste. By the late 1980s solidified defense high-level waste may be available from the Savannah River Laboratory; however, it will not be available until several years after the WIPP experiments are scheduled to begin. To increase its levels of radioactivity this waste could be fortified with strontium-90 or cesium-137. The resulting material would not, however, simulate the chemical properties of commercial waste.

2.4 PROGRAMMATIC ALTERNATIVES TO THE WIPP REFERENCE CASE

2.4.1 Possible Locations, Geologic Environments, and Decision Dates

The NWTS and WIPP programs have identified locations that may be suitable for repositories (Appendices A and B). The continuing NWTS site-qualification* program will describe sites in detail; it is based on recommendations by the Interagency Review Group (IRG 1979, p. 59) that a continuing

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*Site qualification (also called site characterization) is a description in enough detail to undertake an environmental impact analysis.

search for sites suitable for a system of repositories be conducted in a wide variety of potential host rocks with diverse geohydrologic characteristics. Since the purpose of the NWTS program is to identify and qualify locations for a system of repositories, its activities do not depend on the time when the site for the first proposed repository for commercial waste is selected. Any other sites found suitable will simply be held for possible future selection as repository sites.

Within the next 6 years, the NWTS program is expected to qualify or reject one or more sites through stage 4 (site analysis) of the previously described site-selection process (Table 2-1). The earliest possible dates for the qualification of sites are as follows:

Geologic medium and location	Date
Bedded salt 1 (Delaware basin)	Now
Dome salt (Gulf interior region)	1981
Basalt (Hanford)	1981/1982
Bedded salt 2	1982
Bedded salt 3	1983
Various nonsalt media (Nevada Test Site)	1983/1984
Various nonsalt media (non-DOE sites)	1984/1985

Each of these sites will have been taken through stage 3 (site studies--Table 2-1) one or two years earlier than the qualification date. Thus a decisionmaker in late 1982, for example, could probably consider all four of the previously qualified sites as well as some of the remaining sites whose qualification would have passed stage 3.

The dates shown here are optimistic and subject to delay. The sequence of qualifications is more likely to remain correct than the dates, but the sequence would be affected if difficulties delaying the qualification of one site were unique to that site. Although these dates will be used in the following discussion, it is site qualification that is important, not the dates by themselves.

At some point a decision to select a site for an HLW repository will foreclose any further opportunity to construct a repository for TRU waste alone. When this decision will be made cannot be predetermined with certainty since it could, in theory, be made any time between now and the completion of the NWTS site-qualification program in 1984-1985. For convenience of analysis and as an appropriate set of specific examples from the full spectrum of possibilities, the following times are assumed for the dates of the HLW repository decision:

- Now (1979)
- After qualification of basalt at Hanford (1982)
- After completion of entire program (1985)

The first qualification date (1979) is possible only in theory. The status of the program is such that no HLW-repository site has been qualified, and the WIPP reference site is not being considered for an HLW repository. Accordingly, a decision in 1979 is not considered further here.

The second and third dates are generally consistent with the realistic options called HLW strategies II and III in the IRG Report (1979, pp. 49-50; see also Appendix C in this document) and similarly identified and analyzed in the draft generic environmental impact statement on the Management of Commercially Generated Radioactive Waste (DOE, 1979a). Accordingly, they are used here to construct alternatives to be considered for decisions on TRU-waste disposal.

Also requiring consideration in the construction of alternatives are variations in programmatic actions for the disposal of TRU waste and up to 1000 spent-fuel assemblies, including "no action" alternatives. It is submitted, however, that the colocation of a research-and-development facility with at least one of the two disposal facilities is necessary and appropriate; the theoretical alternative of no such colocated activity is not reasonable, given a decision to locate either a first-of-a-kind TRU-waste repository or an ISF. This conclusion is based on the following reasoning:

- Research and development at a specific site is a necessary programmatic element that will help to insure the long-term safety of the disposal there.

- The commitment to remove all nuclear waste brought into the experimental area means that the experiments introduce no long-term environmental risks of their own.

- The near-term environmental consequences of the normal operation of experiments are a small fraction of the normal near-term environmental consequences of the disposal facilities with which it is located (Section 9.2). If the normal consequences of the major facility are deemed acceptable, the experimental program, which will use significantly less material, will introduce little increase in the overall consequences of normal operation.

- Since the disposal facilities are assumed to be licensed, experiments in the colocated research-and-development area will also be subject to the regulatory control of the NRC, thus helping to insure their environmental acceptability.

It is not reasonable to suggest a repository without an associated experimental facility, because the need for site-specific data will not be met. This information, obtained, for example, by accelerated testing on the actual repository environment, is needed to support the safety and efficiency of repository operations and to provide the assurance needed to move from limited, retrievable operations to full-scale, irretrievable operations. It might be argued that a research-and-development facility elsewhere, especially if put into operation early, would provide generic information important to repository design, retrievability features, understanding of waste-rock interactions, and other such technical questions. Such a separate facility would not, however, do away with the need for experiments at the repository itself; it would only provide early leads for the experiments at the repository. Thus it seems prudent to include provision for a research-and-development experimental area in the repository. Building a repository without an associated research-and-development experimental capability is not a meaningful alternative within the context of this environmental impact statement.

2.4.2 Alternatives for TRU-Waste Disposal

The basic "no action" alternative for TRU-waste disposal is taken to be retention at the INEL of the full quantity of readily retrievable TRU waste expected to be at the INEL in 1990. As subalternatives, this material may either

- Continue to be stored as at present for an indeterminate time period or
- Be placed in an improved storage condition at the INEL for the same indeterminate time period.

Both of these variations are described in greater detail in Chapter 3, where their environmental impacts are evaluated.

Consideration has also been given to the possibility of geologic storage at the INEL as a further variation. However, this approach has been discarded for the following reasons:

1. There is no suitable geologic environment at the INEL. The Laboratory is on the Snake River Plain, a swath through the mountains 50 to 100 miles wide. The entire INEL area is underlain by a series of early and late basaltic lava flows interspersed with interbeds of unconsolidated material and sedimentary layers. The Snake River Plain hydrology is characterized by the Snake River aquifer, which is approximately 200 miles long by 30 to 60 miles wide. The aquifer permeability is most pronounced in the upper and lower basaltic flows characterized by voids, fissures, and other fracture networks. The top of the aquifer ranges from 200 to 900 feet below the surface; the thickness of the aquifer is not known precisely, but estimates range as high as nearly a mile. This hydrologic system precludes any attempt to construct a geologic repository or to drill through such an extensive aquifer to underlying rocks.

2. One INEL location that is not located over the aquifer is the Lemhi Range on the north edge of the reservation. This is not considered a promising site. The rocks are basically limestone whose hydrology is unknown; existing mines in the region are troubled by groundwater, and hydrologic connections with the aquifer are suspected.

2.4.3 Alternatives for the ISF

The "no-action" alternatives for TRU-waste disposal in the preceding section do not permit the colocation of an ISF at a TRU-waste disposal site at the INEL, where the geology is not suitable for HLW disposal.

In order to fully define alternatives to the reference case, it is necessary to specify the action to be taken with respect to the ISF. Two possible actions are the following:

- Construction of no ISF. Any data required for HLW disposal that would have been obtained from the ISF would be obtained later in an HLW

repository; a portion of the repository would contain waste emplaced retrievably and monitored by special instruments.

- Construction of a stand-alone ISF elsewhere. By definition, this facility would be neither a TRU-waste repository nor an HLW repository.

While some useful generic information could be obtained from a stand-alone ISF (Appendix C), only a portion of that information could be transferred to another site. The value of such information thus needs to be compared to the value of information obtained otherwise, in view of the high expense, estimated at several hundred million dollars, for a stand-alone ISF. For example, a research-and-development facility, which would not require licensing, could test a smaller number of fuel elements earlier; the cost, estimated at several tens of millions of dollars, would be much lower. Alternatively, information could be obtained at the HLW repository at a somewhat later date. Another opportunity would exist if a combination of the ISF with a dedicated TRU-waste repository (at an incremental cost for colocation estimated at $6 million dollars) were not yet precluded when the HLW repository was selected.

In general, the high cost of a stand-alone ISF argues against it, when other alternatives are available to meet essentially the same or even more extensive objectives at lesser cost. When colocated with a dedicated TRU-waste repository, an ISF permits the acquisition of the important institutional and technical experience summarized earlier in this chapter, and its modest incremental cost appears to represent a reasonable investment. In light of the preceding points, proceeding with a stand-alone ISF at a relatively high cost is not now considered by the Department of Energy to represent an attractive alternative in comparison with the other options. Accordingly, if an ISF is not to be combined with a dedicated TRU-waste repository, the DOE feels that the only attractive alternative is the first one cited above (construction of no ISF). Studies of spent-fuel disposal would then be performed later along with the operation of an HLW repository.

2.4.4 Summary of Alternatives

The seven* actions listed on the next page represent the spectrum of alternatives to the reference case considered in this draft environmental impact statement.

Chapter 3 examines the environmental impacts associated with each alternative, and Chapter 4 assesses the degree to which each alternative satisfies the policy objectives set forth in Section 2.2.4.

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*A stand-alone ISF is not considered an attractive alternative for the reasons given in Section 2.4.3. For the sake of NEPA compliance, it may be considered a partial alternative, and therefore its environmental consequences are discussed in Section 3.7.

TRU-waste action	ISF action	Earliest time for decision
Alternative 1: No action		
No action (i.e., subsurface storage at INEL)	None	Any time until foreclosed
Alternative 2: WIPP reference case		
Dedicated repository (at a site selected from Delaware basin sites)	Colocation	Now
Alternative 3: WIPP reference case without an ISF		
Dedicated repository (at a site selected from Delaware basin sites)	None	Now
Alternative 4: Disposal of TRU waste in the first available HLW repository		
No dedicated repository (dispose of TRU waste at HLW-repository site selected from Delaware basin, Gulf interior, and Hanford sites)	None	Completion of Hanford basalt qualification (1982)
Alternative 5: Delayed and possibly relocated TRU-waste repository with an ISF		
Dedicated repository (at a site selected from Delaware basin, Gulf interior, and Hanford sites)	Colocation	Completion of Hanford basalt qualification (1982) assuming HLW-repository site selection is deferred
Alternative 6: Delayed and possibly relocated TRU-waste repository without an ISF		
Dedicated repository (at a site selected from Delaware basin, Gulf interior, and Hanford sites)	None	Completion of Hanford basalt qualification (1982) assuming HLW-repository site selection is deferred
Alternative 7: Disposal of TRU waste in a late HLW repository		
No dedicated repository (dispose of TRU waste at HLW-repository site selected from full set of NWTS sites)	None	Completion of full set of NWTS site qualifications (1985)

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3 Environmental Impacts of Alternatives

This chapter evaluates and compares the environmental impacts of the various alternatives delineated in Chapter 2. Alternative 1, no action, is the first alternative to be discussed. Next is alternative 2, a Waste Isolation Pilot Plant in southeastern New Mexico, the most completely analyzed of these; it is used as the reference case against which to compare the other alternatives. Its detailed analysis in Chapters 6 and 9 is summarized in Section 3.2. Thereafter the remaining five alternatives are taken up one by one and compared with the reference case. For alternatives that accommodate both defense TRU waste and high-level waste in one repository (alternatives 4 and 7), the point of view is twofold: (1) the changes in impacts (usually increases) associated with expanding the mission of the HLW repository and (2) the changes in impacts (usually decreases) in having one repository rather than two.

3.1 ALTERNATIVE 1: NO ACTION

If neither the WIPP reference repository nor any other Federal repository should become available, TRU waste would have to remain at its present storage sites (or be transferred between them). The consequences of following this alternative are analyzed in Section 9.7 in terms of the problems at the Idaho National Engineering Laboratory (INEL). Three general subalternatives are considered:

1. The waste could be left in place, as is. Additional waste received would be stored similarly.

2. Improved in-place confinement could be provided for the waste. At INEL this would consist of added rip-rap over storage pads and/or grout injected into and under the waste.

3. The waste could be retrieved, processed, and disposed of at a better location at the INEL. Disposal alternatives considered were disposal in an engineered concrete structure and shallow-land disposal elsewhere at the INEL.

In the short term (i.e., up to 100 years), no releases of radiation would be associated with the first two subalternatives. The processing involved in the third would produce in a small release resulting in a maximum whole-body dose commitment of 1.9×10^{-10} rem per year of operation or 3.6×10^{-6} rem per year to the bone at the point (on the INEL site) of maximum airborne concentration. The dominant handling accident would be associated with waste that has not been processed but only repackaged. The resulting maximum dose commitment, to the lung, would be about 4×10^{-9} rem for each occurrence.

Over the long term, natural disasters could occur, disrupting the waste and resulting in the release of radionuclides. The INEL is located at the edge of the Arco Volcanic Rift Zone, which has been active within the last

400,000 years and is likely to be the site of future volcanic action. Therefore the dominant natural disaster would be volcanic action, either an eruption through or near the waste or lava flow over it. Human intrusion is also credible. Table 3-1 gives estimates of the possible radiation doses resulting from these disruptions. Significant dose commitments (up to 100 rem to the bone or lung) could be delivered to maximally exposed individuals if either of the first two subalternatives were to be used.

Improved surface storage (subalternative 3 in Table 3-1) gives the possibility of somewhat lower individual and population dose commitments, but a lung dose of 9 rem, probably delivered in the first year or two, is predicted if lava flows over the storage area.

In summary, no environmental reasons have been found why TRU waste could not be left at the INEL stored as it is for several decades or even a century. In the long term, however, volcanic action that could produce large exposures to radiation is quite probable.

Table 3-1. Possible Long-Term Consequences, Alternative 1

Release mechanism	Individual dose commitment (rem)			Population[a] dose commitment (man-rem)		
	Whole body	Bone	Lung	Whole body	Bone	Lung
Subalternative 1: Waste left as is[b]						
Volcano	0.01	8	20	20	40,000	80,000
Lava flow	0.03	50	90	100	200,000	400,000
Intrusion	0.003	60	60	0.03	500	500
Subalternative 2: Improved confinement[c]						
Volcano	0.0001	0.8	0.2	0.2	400	800
Lava flow	0.0003	0.5	0.9	1	2,000	4,000
Intrusion	0.00003	0.6	0.6	0.0003	5	5
Subalternative 3: Improved disposal after retrieval and processing[d]						
Volcano	0.0001	0.08	0.2	0.2	400	800

[a]Population is 130,000 for volcanic action and lava flow, 10 for human intrusion.
[b]Data from Table 9-60.
[c]Data from Table 9-63.
[d]Data from Table 9-67.

3.2 ALTERNATIVE 2: THE WIPP REFERENCE CASE

A detailed analysis has been made of a Waste Isolation Pilot Plant (WIPP) located in the bedded salt of the Delaware basin in southeastern New Mexico. It is reported in Chapters 6 and 9 and summarized in this section. This alternative is used as the reference against which to compare all other alternatives (except no action) considered in this environmental impact statement.

The impacts of the WIPP include

1. Physical impacts during construction and operation
2. Socioeconomic impacts
3. Radiological impacts of transportation, including transportation accidents
4. Radiological impacts of normal and accidental releases during the time that waste is being emplaced in the WIPP (the short-term, or operational, period)
5. Possible radiological impacts after the WIPP is closed and decommissioned (the long-term period)
6. Impacts of removing waste from its present storage and processing it for shipment to the WIPP

The mission of the WIPP reference repository is concerned only with the TRU waste stored at the INEL. This analysis, however, in order to keep the choice available, assumes that the contact-handled-waste level of the repository will eventually be filled to capacity. It also assumes that no more than 1000 spent-fuel assemblies are ever disposed of in the repository.

Even though no more than 1000 spent-fuel assemblies are to be stored in the WIPP, there is a greater amount of radioactivity initially associated with them than with the TRU waste, even if the TRU repository is filled to capacity (Table 3-2). However, the mix of radionuclides for the two forms of waste differs; spent fuel will have more of the shorter-lived actinides than defense TRU waste. Thus the ratio of actinide activity in the spent fuel to that in the TRU waste will decrease, and in a full repository there will eventually be more actinide activity associated with the TRU waste than with the spent fuel.

3.2.1 Physical Impacts

Physical impacts of the reference case would occur primarily during construction and operation. These impacts are summarized in Table 3-3.

Commitment of the reference site for repository development would primarily affect grazing; the land surface currently has few other uses. National and local food production would sustain no appreciable loss, for the 980 acres affected normally support fewer than 10 head of cattle.

Table 3-3 loosely categorizes surface land use as "temporary" and "long-term." Probably the only long-term use that would be truly permanent is the

land to be used for the mined-rock (salt) pile; these 30 acres, sterilized by salt, would not support grazing again. The other parcels of land included in the long-term category are rights-of-way for roads and railroads and the land occupied by buildings. After the project is over, this area would largely regain its natural vegetation if the buildings are razed. The temporary category includes the rights-of-way for electricity and water lines because the land on which they are built would be allowed to return to its natural vegetated state after these lines are constructed.

Table 3-2. Actinide Activity in the WIPP Reference Repository

Source	Activity (Ci) CH level loaded only with INEL stored waste	CH level fully loaded with TRU waste
ISF--1000 spent-fuel assemblies		
Fission products at time of loading	153×10^6	153×10^6
Actinides		
At time of loading	34×10^6	34×10^6
1000 years later	733×10^3	733×10^3
TRU waste[a]		
Actinides		
At time of loading	345×10^3	10×10^6
1000 years later	57×10^3	1.7×10^6
Actinide ratios: spent-fuel/TRU waste		
At time of loading	99	3.3
1000 years later	13	0.4

[a]Waste volume 2.4×10^6 ft^3 if CH level is loaded only with INEL stored waste and 70×10^6 ft^3 if CH level is fully loaded with TRU waste.

The resources to be used in building and operating the reference repository are a commitment of materials that could be used elsewhere. Supplying the resources listed in Table 3-3 would not, however, strain the resources of the nation, the state, or the local area. All are small compared to the annual production of these resources in the United States.

Most of the effluents from the plant would have little effect on the environment, although salt dust from the mined-rock pile and from mining would have effects like those of a normally operating salt or potash mine--that is, suppression of some species of plants nearby. Sewage treatment and the disposal of solid wastes in a local landfill would be much smaller than the familiar operations carried out by cities. The effluents listed in Table 3-3 come mostly from the operation of diesel equipment in the plant.

The impacts of the radioactive effluents listed are given in Section 3.2.4 below.

Table 3-3. Physical Impacts of the WIPP Reference Case

Parameter	Quantity			Section
Use of land surface				
Temporary	360 acres			9.1.1.1
Long-term	620 acres			9.1.1.1
Resources				
Materials for construction[a]				
Concrete	125,000 bbl cement	0.032%	of U.S. production per year	9.1.2.2
Steel	15,000 tons	0.012%		9.1.2.2
Copper	150 tons	0.009%		9.1.2.2
Aluminum	200 tons	0.003%		9.1.2.2
Lumber	0.5 x 10^6 board feet	0.0005%		9.1.2.2
Water				
Construction	17 acre-ft/yr	0.3%	of Carlsbad use	9.1.2.1
Operation	20 acre-ft/yr			9.2.2
Electricity				
Construction[a]	4 x 10^6 kW-hr			9.1.2.3
Operation	2 x 10^4 kW			9.2.2
Liquid fossil fuels				
Construction[a]	2.6 x 10^6 gal			9.1.2.3
Operation	540 gal/day			9.2.2
Effluents				
Construction period				
Carbon monoxide	26 tons/yr	0.1%	of Eddy County emissions	9.1.1.4
Hydrocarbons	8 tons/yr	0.9%		9.1.1.4
Nitrogen oxides	142 tons/yr	2.4%		9.1.1.4
Aldehydes	2 tons/yr			9.1.1.4
Sulfur oxides	9 tons/yr	0.04%		9.1.1.4
Particulates	5 tons/yr	0.02%		9.1.1.4
Operational period				
Carbon monoxide	9.7 tons/yr	0.1%	of Eddy County emissions	9.2.9.3
Nitrogen oxides	50 tons/yr	0.83%		9.2.9.3
Sulfur oxides	30 tons/yr	0.13%		9.2.9.3
Hydrocarbons	3.2 tons/yr	0.04%		9.2.9.3
Particulates	3.2 tons/yr	0.02%		9.2.9.3
Salt into air	1050 lb/yr			8.7.5, 9.2.9.3
Solid, nonradioactive waste (uncompacted)	2500 yd^3/yr			8.7.2
Sanitary waste (treated effluent)	25,000 gal/day			9.2.9.1
Radioactive				
Solid (spent resins)	460 ft^3/yr			8.5.2
Gaseous	9.3 Ci/yr			8.6
Mineral reserves				
In entire withdrawal				
Sylvite	3.7 x 10^6 tons K_2O	1.8%	of U.S. reserves	9.1.4.4
Langbeinite	4.4 x 10^6 tons K_2O	11.6%[a]		9.1.4.4
Crude oil	0			
Natural gas	37 x 10^9 cubic feet	0.02%		9.1.4.4
Distillate	0.55 x 10^6 barrels	0.0015%		9.1.4.4
In inner zones				
Sylvite	0			
Langbeinite	1.2 x 10^6 tons K_2O	3.2%[b]	of U.S. reserves	9.1.4.7
Crude oil	0			
Natural gas	23.5 x 10^9 cubic feet	0.01%		9.1.4.7
Distillate	0.35 x 10^6 barrels	0.001%		9.1.4.7

[a]For a four-year construction period.

[b]Percentage based on an unofficial estimate (i.e., not made by the U.S. Geological Survey) of langbeinite reserves. See Section 9.1.4.4.

Development of most of the subsurface mineral reserves* listed in Table 3-3 would be denied temporarily; all of the sylvite, three quarters of the langbeinite and about a third of the natural gas and distillate will eventually be released for exploitation. Section 8.1.2 presents the rules under which some of the subsurface development rights could be restored: mining other than solution mining and drilling for oil and gas would probably be allowed in the outer control zone. The natural gas listed might well be more completely recovered because drilling outside the controlled zones would tap pools that extend in under those zones. It is uncertain at this time when this relaxation of restriction of access could be granted, but it could be several decades. Although langbeinite is a useful fertilizer, it is not essential in agriculture; substitutes for it exist.

In summary, the most important physical impacts of development of alternative 2, the WIPP reference case, would be the use of land, especially that required for the waste salt pile, and the denial of access to subsurface mineral reserves. The most important of these reserves is the potassic mineral langbeinite, used for fertilizer where chlorides cannot be used.

3.2.2 Socioeconomic Impacts

These impacts are summarized in Table 3-4 from information given more fully in Section 9.4.

Table 3-4. Socioeconomic Impacts of the WIPP Reference Case in Eddy and Lea Counties

Impact	Construction[a]	Operation[b]	Source Section
Expenditures[c]			
Direct	$ 95.9 million	$14.3 million	9.4.1.1
Indirect	$ 32.7 million	$16.2 million	9.4.1.1
Total	$128.6 million	$30.5 million	9.4.1.1
Jobs			
Direct	1307[d]	444	9.4.1.3
Indirect	1834[d]	661	9.4.1.3
Total	3141[d]	1105	9.4.1.3
Population changes			
Direct	1700	650	9.4.2.1
Indirect	1350	550	9.4.2.1
Total	3050	1200	9.4.2.1

[a]Total costs for the whole 4-year period of construction.
[b]Annual costs.
[c]1977 dollars. Multiply by 1.5 for 1983 dollars.
[d]Peak year.

*Reserves are those portions of resources recoverable under today's economic conditions using today's technology.

The WIPP reference repository would cost about $225 million to build and about $36 million a year to operate (1978 dollars). In addition, it will cost $205 million for engineering, construction management, and technical support. A little under a half of the first two costs would be spent locally. Thus during the period of construction (assumed in the analysis to be 42 months), the economy of Eddy and Lea Counties would receive $95.9 million in direct new expenditures for labor and local procurement. Indirect or spinoff effects in the private sector of an additional $32.7 million would occur. During repository operation, the total direct and indirect impact on the private sector of the economy would be about $30 million annually.

New jobs would be created. These would peak in 1983 (assuming that construction starts in 1981), when as many as 1300 people would be employed on the project and about 1800 jobs would be indirectly created. This total will drop back to 444 direct and 660 indirect jobs during operation. About half of these people would be hired locally. As a result there will be an increase in population in the area that at one time will be 3050 but during operation will drop back to 1200.

Two alternative assumptions were made in the socioeconomic analysis. The first assumes the current pattern of housing for potash-industry workers: the work force lives mostly in Carlsbad, which receives by far the major impact of the project. The second assumes that a significant fraction of the workers live in Lea County: Hobbs then receives more than one-third of the impacts.

Under the first assumption, there may be a temporary housing shortage in Carlsbad during the peak construction period. Community services there are judged to be adequate, although the fire and police forces would have to be increased to meet the needs of the increased population.

Under the second assumption, housing in Hobbs would keep up with demand, but would have to spread beyond the present city limits and municipal utilities. At Hobbs as at Carlsbad, fire and police forces would have to be expanded.

3.2.3 Radiological Impacts of Transportation

These impacts are summarized in Table 3-5 from information given more fully in Sections 6.6 and 6.7.

Although the mission of the WIPP reference repository is to dispose of the TRU waste stored at Idaho and to demonstrate the disposal of spent fuel in the ISF, the analysis of transportation effects assumed waste received from a number of sources around the country since the plant would be constructed with the capability of storing TRU waste from Idaho, Hanford, Los Alamos, Savannah River, Rocky Flats, and Oak Ridge and spent fuel from Morris, Illinois. (The source of spent fuel has not been decided; Morris is taken as representative of possible sources. The source of waste for experiments may be Hanford, Oak Ridge, or Savannah River.) There would be about 1000 shipments a year to this repository, distributed among types of waste as indicated in Table 3-5.

Table 3-5. Radiological Impacts of Transportation

Exposure during accident-free transportation

Waste type	Number of shipments per year	Population exposure (man-rem/yr)
CH TRU	825	9.9
RH TRU	162	4.7
Spent fuel[a]	82	2.8
Total	1069	17.4

Exposure during accidents: Dose to an individual[b]

Scenario	Dose commitment (rem)		
	Bone	Lung	Whole body
CH TRU rail	0.49	0.025	0.012
CH TRU truck	0.59	0.029	0.014
RH TRU	0.00003	0.000007	0.00003
Spent fuel[a]	1.2	0.30	1.1

Exposure during accidents: Dose to a small urban area[c]

Scenario	Dose commitment (man-rem)		
	Bone	Lung	Whole body
CH TRU rail	1700	83	40
CH TRU truck	2000	99	48
RH TRU	0.1	0.024	0.090
Spent fuel[a]	4200	1000	3700

Exposure during accidents: Dose to a large urban area[d]

Scenario	Dose commitment (man-rem)		
	Bone	Lung	Whole body
CH TRU rail	3700	190	90
CH TRU truck	4500	220	110
RH TRU	0.22	0.052	0.20
Spent fuel[a]	9400	2300	8300

[a]Until the full quota of spent fuel is in place.
[b]Maximum dose to an individual one-half mile from the accident.
[c]Approximately 6000 people are affected by the plume.
[d]Approximately 105,000 people are affected by the plume.

Sources: Sections 6.6.3 and 6.7.3.

In normal, accident-free transportation, the persons exposed would be the truck and train crews and persons passed en route. The greatest exposures would be to truck drivers because of their closeness to their cargo: a total of about 55 man-rem to 1300 persons, or an average of 40 mrem per trip per person. This dose level is one-half to one-third of that received annually from natural background radiation and well within the 5000 mrem/yr permitted to radiation workers. The exposure of train crews would be much less, 0.22 man-rem/yr. The dose to the general public, 17.4 man-rem/yr, is spread over several million people and is thus less than 0.01% of that received from natural background radiation.

Most transportation accidents would not be severe enough to release any radioactivity at all because of strict Department of Transportation (DOT) regulations on packaging for shipment. Statistics show that only 0.5% of truck accidents and 0.4% of rail accidents have impacts more severe than those that the regulations provide protection against, and fewer than 0.2% have fires as severe. While the total number of accidents statistically expected, at all levels of severity, is about 8 per year, an accident exceeding in severity the conditions specified in DOT regulations can be expected only about every 37 years (Section 6.7.3).

For the analysis, maximum accidents were hypothesized under conditions that reduce their probability to less than one in 10,000 years. They were assumed to happen in a small (30,000 people) or medium-sized (300,000 people) city. They were assumed to happen under atmospheric conditions that would hold the plume of released material together and blow it in the direction of the densest population, thus maximizing the concentration of material. Details are given in Section 6.7.2.

Table 3-5 indicates that an accident like those assumed might produce individual 50-year dose commitments (to the bone) of 1.2 rem. These are on the order of 25% of the dose commitments from natural background radiation in the same 50 years.

3.2.4 Radiological Impacts During Plant Operation

These impacts are summarized in Tables 3-6 and 3-7 from analyses described in more detail in Sections 9.2.10 and 9.3.1.

Table 8-6 in Section 8.6.2 indicates that in normal operation 9.3 Ci/yr of activity might be released from the facility. Most of this (7.8 Ci) would be krypton-85 from spent fuel; it is arbitrarily assumed that one spent-fuel canister would be received damaged during the time such shipments would last. If no such damaged spent-fuel canister were received, the total release would drop to about 1 Ci/yr, almost all from natural radon released by mining. The total release from stored waste then would be 4×10^{-3} Ci/yr.

The consequences shown in Table 3-6 are very small. The maximum individual dose (to the bone) is only 0.003% of that received from natural background radiation. The whole-body commitment is 7.6×10^{-5}% of background.

A number of possible operational accidents were studied, and Table 3-7 shows the doses that the worst of these would deliver to a person at the

Table 3-6. Radiological Impacts of Normal Plant Operation

Dose or Dose Commitment Received by an Individual Residing at the James Ranch, the Nearest Inhabited Point

Group	Dose or dose commitment (rem)		
	Bone	Lungs	Whole body
Structural materials	7.7×10^{-10}	6.5×10^{-10}	6.9×10^{-10}
Fission products	9.7×10^{-8}	1.2×10^{-8}	2.8×10^{-8}
Actinides	1.5×10^{-4}	7.1×10^{-6}	3.7×10^{-6}
Spent fuel	3.4×10^{-8}	3.5×10^{-8}	3.4×10^{-8}
Total	1.5×10^{-4}	7.1×10^{-6}	3.8×10^{-6}
Natural background	5.0	9.0	5.0

Dose or Dose Commitment Received by the Population Within 50 Miles of the WIPP[a]

Group	Dose or dose commitment (rem)		
	Bone	Lungs	Whole body
Structural materials	2.7×10^{-6}	2.0×10^{-6}	2.2×10^{-6}
Fission products	9.2×10^{-4}	3.9×10^{-5}	2.4×10^{-4}
Actinides	4.8×10^{-1}	2.2×10^{-2}	1.2×10^{-2}
Spent fuel	1.1×10^{-4}	1.2×10^{-4}	1.2×10^{-4}
Total	4.8×10^{-1}	2.2×10^{-2}	1.2×10^{-2}
Natural background	4.8×10^{5}	8.6×10^{5}	4.8×10^{5}

[a]The population within 50 miles of the WIPP is 96,000.

Source: Section 9.2.10.2.

nearest inhabited point, James Ranch, just outside the boundary of the site to the south-southwest. The worst accident is a drop of a spent-fuel canister in the waste shaft. It could expose a person living at the James Ranch to a lung-dose commitment of 0.0001% of background or to a skin dose of 0.22% of background.

3.2.5 Possible Long-Term Impacts

During the long term after the WIPP ceases operation and is closed up, the expected release of radioactive material is zero.

Nevertheless, there are a number of possible man-made and natural events that could cause such a release. High among them are the drilling of holes and failures of plugs in shafts or holes. The probabilities of such events are very difficult to determine and are therefore not available. The analysis in this document instead assumes that such breaks in repository integrity do occur and assesses their consequences (Section 9.5.1).

Table 3-7. Radiological Impacts of Operational Accidents

Dose or Dose Commitment Received by an Individual Residing at the James Ranch, the Nearest Inhabited Point[a]

Accident scenario	Dose or dose commitment (rem)				
	Bone	Lung	Whole body	Skin	Thyroid
CH Area					
Hoist drop	7.8×10^{-9}	3.9×10^{-10}	1.8×10^{-10}		
Underground fire	1.1×10^{-8}	5.5×10^{-10}	2.6×10^{-10}		
RH Area					
Hoist drop					
Experimental HLW	2.5×10^{-8}	2.4×10^{-9}	1.5×10^{-9}		
Spent fuel	8.7×10^{-6}	1.0×10^{-5}	8.3×10^{-6}	2.2×10^{-4}	3.2×10^{-5}
Underground fire	7.2×10^{-8}	5.7×10^{-9}	3.3×10^{-9}		
Natural background	5.0	9.0	5.0	0.1	4.0

Dose or Dose Commitment Received by the Population in the "Worst Sector"[a]

Accident scenario	Dose or dose commitment (man-rem)				
	Bone	Lung	Whole body	Skin	Thyroid
CH Area					
Hoist drop	1.8×10^{-5}	9.2×10^{-7}	4.3×10^{-7}		
Underground fire	2.5×10^{-5}	1.3×10^{-6}	6.1×10^{-7}		
RH Area					
Hoist drop					
Experimental HLW	5.8×10^{-5}	5.4×10^{-6}	3.4×10^{-6}		
Spent fuel	2.0×10^{-2}	2.3×10^{-2}	1.9×10^{-2}	5.1×10^{-1}	7.4×10^{-2}
Underground fire	1.6×10^{-4}	1.3×10^{-5}	7.5×10^{-6}		
Natural background	$1.4 \times 10^{+5}$	$2.6 \times 10^{+5}$	$1.4 \times 10^{+5}$	$2.9 \times 10^{+3}$	$1.1 \times 10^{+5}$

[a]Population = 6.
[b]28,700 people live in the "worst sector."

Source: Section 9.3.1.

Table 3-8 tabulates the most severe consequences found. Scenario 1 assumes an open hole that connects water-bearing rocks above and below the waste-storage levels and that admits flowing unsaturated water to the waste. Scenario 4 is a so-called bounding case, the worst imaginable, in which all the water in the rocks of the overlying Rustler Formation is diverted down to the waste levels and then back up into its original course. Scenario 5 assumes that drilling into the repository brings material to the surface to expose the drill crew directly and people in a downwind farm indirectly. In both cases, the dose or 50-year dose commitment to the maximally exposed individual is shown.

Scenarios 1 and 4 produce exposures of no more than 2% of background. Spent fuel in the repository gives greater doses than CH TRU waste because the former contains iodine-129 and technetium-99, and the latter does not.

Table 3-8. Consequences of Possible Long-Term Releases of Radiation (Doses to Maximally Exposed Individuals)

Scenario[a]	Type of dose	Consequences to bone		Consequences to whole body	
		Spent fuel	CH TRU waste	Spent fuel	CH TRU waste
1[b]	Dose (rem/yr)	2.1×10^{-4}	4.5×10^{-6}	3.0×10^{-5}	1.2×10^{-6}
4[b]	Dose (rem/yr)	2.1×10^{-3}		4.0×10^{-4}	
5 (direct)[c]	Dose from single exposure (rem)	0	0	8.8	1×10^{-3}
5 (indirect)[c]	50-year dose commitment (rem)	0.7 (to lung)	3.6×10^{-5}	4.3×10^{-2}	9.4×10^{-7}

[a] As defined in Section 9.5.1.3.
[b] Initiating event at 1000 years.
[c] Drill-through at 100 years.

Source: Section 9.5.1.

Scenario 5 presents the possibility of doses appreciably higher than those received from natural background radiation. It presumes coring right through the stored waste and exposing the geologist who examines the core to a dose of 8.8 rem, 1.8 times a permissible year's occupational exposure. All other persons would receive much lower doses: if there were a farm nearby, an improbable development, people there could be exposed to dose commitments of 8% of background at most.

The heat released from 1000 canisters of spent fuel would cause the ground surface to rise about 3 centimeters over a period of 1000 years. It would cause the temperature of the overlying Rustler Formation aquifers to rise about 3°C and that of the underlying Bell Canyon Formation aquifers to rise about 0.2°C.

As the mined cavities close, an area of about 4000 acres over the repository will subside slowly. At the center of this area the surface may sink by as much as 50 centimeters. Because the natural variations in the terrain are greater, this subsidence will be little noted.

3.2.6 Impacts of Removing TRU Waste from Storage

Removal of TRU waste from its present storage pads at the Idaho National Engineering Laboratory is analyzed in Section 9.6 and summarized in Table 3-9.

The analysis also includes processing by slagging pyrolysis to meet waste-acceptance criteria.

The largest radiological impacts from each year of normal operation would be dose commitments of 0.0036 mrem (bone) and 0.00000002 mrem (whole body) to

Table 3-9. Radiological Consequences of Removing Waste from Storage and Preparing for Shipment

Process and release event	Individual dose commitment			Population dose commitment		
	Whole body	Bone	Lung	Whole body	Bone	Lung
			Normal operation[a]			
Retrieval	2.4×10^{-14}	4.6×10^{-10}	4.5×10^{-10}	2.9×10^{-10}	4.2×10^{-6}	4.1×10^{-6}
Processing	1.9×10^{-10}	3.6×10^{-6}	3.5×10^{-6}	2.3×10^{-6}	3.3×10^{-2}	3.3×10^{-2}
			Accident[b]			
Retrieval	6×10^{-7}	3×10^{-4}	4×10^{-4}	8×10^{-4}	4×10^{-1}	8×10^{-1}
Processing						
Waste preparation	2×10^{-8}	1×10^{-5}	2×10^{-5}	4×10^{-5}	2×10^{-2}	4×10^{-2}
Pyrolysis	1×10^{-4}	7×10^{-2}	1×10^{-1}	2×10^{-1}	$1 \times 10^{+2}$	$2 \times 10^{+2}$
Packaging and loading	1×10^{-7}	7×10^{-5}	1×10^{-4}	2×10^{-4}	1×10^{-1}	2×10^{-1}
Background (50-yr)	7.5			$1 \times 10^{+6}$		

[a]Individual dose commitments are given in rem per year; population dose commitments are in man-rem per year.

[b]The accident is fire with loss of building containment. Individual dose commitments are given in rem per incident; population dose commitments are in man-rem per incident.

the maximally exposed person and 0.033 man-rem (bone) and 0.0000023 man-rem (whole body) to the surrounding population. This release would be from processing by slagging pyrolysis.

The maximum dose commitments from accidents would be 0.1 rem (lung) and 0.0001 rem (whole body) to the maximum individual and 200 man-rem (lung) and 0.2 man-rem (whole body) to the surrounding population. The worst accident would be a fire coupled with loss of the confinement afforded by the surrounding building. The worst place for a fire to occur would be in the temporary structure erected around a storage pad during retrieval.

The radiological effects of these exposures would be far smaller than the corresponding effects from natural background radiation. Nonradiological effects would be limited to relatively minor commitments of manpower and other resources.

3.2.7 Summary of Major Impacts

The largest impacts entered in Tables 3-3 through 3-9 are brought together in Table 3-10. Each impact but the first two is compared with some relevant standard, such as an existing condition without the WIPP. Radiation doses, for example, are compared with the doses received from natural background radiation.

The largest adverse impacts listed are the following:

1. Denial of mineral reserves. About one-thirtieth of the known U.S. reserves of the mineral langbeinite will be kept from exploitation for

Table 3-10. Summary of Major Impacts of the Reference Repository

Physical impacts			
Land use			
Temporary	360 acres		
Long term	620 acres		
Mineral reserves--langbeinite			
Temporary denial	4.4 x 10^6 tons K_2O	11.6%	of U.S. reserves
Long-term denial	1.2 x 10^6 tons K_2O	3.2%	of U.S. reserves
Socioeconomic impacts			
Jobs, direct and indirect			
Peak	3141	7.4%	of the two-county employment
Long term	1105	2.6%	of the two-county employment
Population changes, direct and indirect			
Peak	3050	3.1%	of the two-county employment
Long term	1200	1.2%	of the two-county employment
Transportation impacts			
Normal, accident-free			
Population dose	17.4 man-rem/yr	10^{-3}%	of background
Accidents, maximum bone-dose commitment			
Individual	1.2 rem	25%	of 50-year background
Small-town population	4200 man-rem	14%	of 50-year background
Medium-town population	9400 man-rem	1.9%	of 50-year background
Impacts of normal plant operation			
Bone-dose commitment			
Individual	1.5 x 10^{-4} rem	0.003%	of 50-year background
Population, worst sector	0.48 man-rem	0.0001%	of 50-year background
Impacts of operational accidents			
Spent fuel, broken canister			
Individual (skin)	2.2 x 10^{-4} rem	0.2%	of annual background
Population (skin)	0.51 man-rem	0.02%	of annual background
CH TRU waste, fire			
Individual (bone)	1.1 x 10^{-8} rem	2 x 10^{-7}%	of 50-year background
Population (bone)	2.5 x 10^{-5} man-rem	2 x 10^{-8}%	of 50-year background
Long-term impacts			
Expected release	0		
Drilling[a] through spent fuel			
Crew member (whole-body dose)	8.8 rem	180%	of permitted 1-year occupational exposure
Farmer (lung-dose commitment)	0.7 rem exposure	8%	of background
Drilling[a] through CH-TRU waste, exposed farmer (bone-dose commitment)	3.6 x 10^{-5} rem	0.0007%	of background
Water carries waste to biosphere,[b] maximally exposed person (bone-dose commitment)	0.002 rem/yr	2%	of background

[a]Drilling 100 years after repository sealing, bringing waste to surface.
[b]Worst hypothetical accident analyzed.

a long time, possibly several decades. Substitutes can, however, be extracted from brine lakes.

2. Possible accidents during transportation. An accident in transporting TRU waste could deliver to a nearby individual a 50-year dose commitment as large as 25% of the dose commitment delivered by natural background radiation.

3. Possible long-term releases of radioactivity. If people were to drill into the stored spent fuel 100 years after the repository is sealed, the drill-crew geologist would be exposed to a radiation dose of 1.8 times a year's permissible occupational dose.

3.3 ALTERNATIVE 3: THE WIPP REFERENCE CASE WITHOUT AN INTERMEDIATE-SCALE FACILITY (ISF)

The environmental impacts summarized in Section 3.2 are those to be expected from the WIPP reference case discussed in Section 2.3, including the demonstration of spent-fuel disposal in the ISF section of the underground workings. If the demonstration is deleted from the mission, the spent-fuel assemblies will not be shipped to the WIPP site; they will remain stored in pools until another ISF or an HLW repository is built. Without these assemblies, the environmental impacts of the WIPP will not include the impacts that would have resulted specifically from operation of the ISF. Organized according to the outline of Section 3.2, this section describes the changes that deleting the ISF will bring about in the predicted environmental impacts of the reference repository.

Physical impacts

Because the ISF will occupy only 20 acres of the WIPP lower underground level, omitting it from the design would have little effect on the environmental impacts of excavation. Omitting the ISF would reduce by less than 1% the volume of the mined-rock pile that will hold the material brought to the surface during excavation. This small decrease in volume would produce no significant change in the limited environmental impacts (Section 9.1.3) expected from the pile.

Similarly, the omission of the ISF would have little effect on the design and operation of the plant, which will accommodate remotely handled waste even if it receives no spent fuel. Of the impacts summarized in Table 3-3, land use and denial of mineral resources would not change; commitment of resources and release of effluents would change by a fraction of 1%.

Section 9.2.7 discusses the effects that the heat from spent fuel will exert during WIPP operation. It predicts that the heat will slightly accelerate the closing of the cavities in which the spent fuel is emplaced and that the temperature at the upper level, where CH waste is stored, will rise by less than 2°C. Without the ISF neither of these effects will occur.

Socioeconomic impacts

The changes in socioeconomic impacts because of the omission of the ISF would arise from decreased expenditures for excavation and waste handling. The savings in excavation are estimated at $400,000, the cost of constructing the 20-acre area underground.

Because the reduction in mined volume would be less than 1%, mining during the operation of the plant would barely be affected, and the full 109 mining jobs shown in Table 9-28 would remain filled. Of the remaining 335 workers needed for the full WIPP mission, few would handle spent fuel, which is to be received at a rate of about 1 package per working day during the first 4 years of operation. The savings from the reduced costs of handling and services might reach $6 million, spread over these 4 years.

Transportation impacts

Table 3-5 summarizes the annual radiation doses to people along the transportation routes. During normal, accident-free transportation, the contributions from spent fuel are smaller than those from remotely handled and contact-handled TRU waste; eliminating the ISF would eliminate nearly 20% of the annual dose from transportation. This reduction would occur, however, only over the period of about 4 years when spent fuel will be shipped to the WIPP; after all the spent-fuel assemblies have arrived, there will be no further impacts of their transportation. Even more important, the predicted population dose including the effects of spent fuel is only 17.4 man-rem per year spread over several million people.

Omitting the ISF would eliminate the remote possibility that an accident during transportation might release radioactivity from a spent-fuel package. The analysis in Section 6.7 postulates several highly unlikely accidents during transportation of waste to the WIPP; the consequences of the accidents involving spent fuel are appreciably greater than the consequences of the accidents involving contact-handled TRU waste (Table 3-5). Because there will be far fewer shipments of spent fuel each year (Section 6.5) and because they will occur only during a 4-year period, the risks from accidents with spent fuel will not be comparable to those with TRU waste.

Impacts during operation

Table 3-6 summarizes the impacts of routine release of radioactivity from the WIPP; it shows the resulting doses and dose commitments, all of which are negligible compared to those received from natural background radiation near the site. These impacts are dominated by the effects of actinides. According to the analysis in Section 8.6.2, the actinides contained in spent fuel do not contribute appreciably to the total amount of actinides released in normal plant operation. While eliminating the ISF would eliminate the doses labeled "spent fuel" in Table 3-6, it would not change the total doses listed there.

Leaving the spent fuel in storage pools implies a small cost in materials and energy and in personal radiation exposure. Such storage is estimated to give a worldwide population exposure of 10^{-7} of background and average workforce exposures of 0.4 rem/yr-person, or 40% of the permissible annual occupational exposures (DOE, 1978, pp. VIII-2 and III-27).

Table 3-7 predicts the consequences of hypothetical severe accidents during WIPP operation; it shows doses and dose commitments to a person at the residence nearest the WIPP and to the population in the most severely affected sector. Deleting the ISF from the WIPP plans would eliminate the possibility of the postulated accident with the most severe consequences: a drop of a spent-fuel canister down the mine shaft. According to Table 3-7, the next-most-serious accident would produce an individual dose commitment that is smaller by a factor of more than 100; the population dose commitment would be similarly reduced. Although these reductions appear appreciable, they are changes in impacts that are far smaller than the impacts of natural background radiation.

Possible long-term impacts

Table 3-8 summarizes the impacts of unexpected hypothetical releases of radioactivity from the WIPP after the repository is decommissioned. It describes these consequences separately for the spent fuel and for the contact-handled TRU waste at the WIPP. Although none of the predicted consequences are appreciable compared to those of natural background radiation, the spent-fuel releases have the more severe impacts. If there is no spent fuel in the WIPP, the predicted bone dose delivered in scenario 1 to a maximally exposed person would be reduced by a factor greater than 40. Because the predicted doses are much smaller than the doses from natural background radiation, however, the reduction would not be appreciable. Even in the bounding analysis (scenario 4), which predicts an unrealistically high upper bound to the WIPP impacts, the total contribution of spent fuel is only about 2% of the contribution of natural background radiation. Eliminating the ISF would therefore remove an environmental impact that would be small even if the ISF is built at the WIPP and if a highly unlikely breach of the repository occurs.

Table 3-8 also presents the consequences of an unlikely sequence of events (scenario 5) in which a drill penetrates the repository and brings waste to the surface. If there is no spent fuel for the drill to penetrate, the predicted doses are much smaller because they are then due only to contact-handled waste. Although dramatic, such reductions would apply to the impact of an event of low probability.

The heat released by spent fuel will, according to Section 9.5.2.1, exert minor long-term effects on temperatures in the nearby rock formations and at the surface; it may temporarily produce a 3-centimeter uplift of the surface and similar displacements underground. Occurring over roughly 1000 years, these effects will have little environmental impact. Eliminating the ISF would, however, eliminate them.

Summary

If no ISF is built in the WIPP, some of the environmental impacts will be changed. There will be no significant change in the impacts of plant construction, in the expected socioeconomic effects, in the effects due to heat produced by the spent fuel, or in the effects of radioactivity released during normal plant operation. The impacts of normal waste transportation will be slightly reduced. Spent fuel also contributes to the releases hypothesized in studies of unexpected events--accidents at the plant, accidents during transportation, and breaches of the repository in the far future. None of these

releases, however, produce population dose commitments comparable to those of natural background radiation.

Although it is possible to predict the reductions due to elimination of the ISF from the WIPP plans, none of the reductions significantly affect the predicted environmental impacts of the full WIPP reference mission.

3.4 ALTERNATIVE 4: DISPOSAL OF TRU WASTE IN A REPOSITORY FOR HIGH-LEVEL WASTE

Under alternative 4, no repository dedicated to the disposal of TRU waste is built. Instead, TRU waste from the national defense program is held until a repository for high-level waste (HLW) is built. Then the defense TRU waste is disposed of in the HLW repository. The three sites that could be considered for an HLW repository in 1982, if the current HLW strategy is pursued, will be in the bedded salt of the Delaware basin, in a salt dome in the Gulf interior region, and in a deep basalt formation at the Hanford Site. Thus for purposes of this analysis it is assumed that the defense TRU waste is emplaced in an HLW repository at one of these sites.

The impacts of alternative 4 are presented from two points of view: (1) the local changes in impacts (usually increases) associated with expanding the mission of an HLW repository to include TRU-waste disposal and (2) the overall national changes in impacts (usually decreases) in having one combined repository rather than two separate ones. The two separate repositories are the WIPP reference repository and an HLW repository.

To present impacts from either point of view, predictions of the impacts of HLW repositories are needed. To get them accurately would require for each site the results of detailed explorations and at least a conceptual design for the plant to be built there. Programs now investigating the disposal of high-level waste in salt and in basalt will eventually produce these basic data and a thorough prediction of impacts. These programs are, however, still in early stages: no specific sites have been selected, and no conceptual designs are available. In this section the discussion of HLW-repository impacts is therefore based largely on environmental impacts predicted generically in the GEIS, the draft generic environmental impact statement for Management of Commercially Generated High-Level Waste (DOE, 1979). The information from the GEIS is supplemented where possible by recent data or estimates from the ongoing programs. The predictions available from these sources are the impacts of the HLW repositories alone, without the addition of defense TRU waste.

Thus, the predictions of impacts used in this section are of different quality. Predictions of impacts of an HLW repository are from the GEIS. Predictions of impacts of the WIPP reference repository are from Chapters 6 and 9 of this document and the summary in Section 3.2. No predictions of the impacts of an expanded repository for HLW and TRU waste have been published; those used here are ad-hoc estimates for an HLW repository like those described in the GEIS but modified and enlarged to accept the defense TRU waste (and spent fuel) that would go to the WIPP if there were separate repositories.

Tables 3-11 and 3-12 present the impacts of alternative 4 from the two points of view. The tables are qualitative summaries; detailed, quantitative tables are premature because of the uncertainties in site characteristics and plant designs. Table 3-11 describes changes in the predicted local impacts of an HLW repository if it is expanded to accept TRU waste. Table 3-12 describes differences in impacts on a national scale. Under alternative 4 no impacts are exerted at the WIPP reference site. By combining the impacts of the WIPP reference repository with those at the expanded HLW repository, alternative 4 would generally achieve a reduction in overall impacts; for this reason most of the entries in Table 3-12 are decreases.

This section explains the entries in Tables 3-11 and 3-12. It begins with a resume of the plant designs assumed for the expanded repositories, describing briefly the additions necessary to convert the HLW-repository designs assumed in the GEIS. Then it describes environmental impacts according to the outline of Section 3.2.

Assumptions

Each of the expanded repositories receives spent fuel and a lesser amount of other HLW waste such as cladding; it handles about 100 HLW packages per day. It receives defense TRU waste at the rates proposed for the WIPP: 1.2 million cubic feet per year of contact-handled waste and 10,000 cubic feet per year of remotely handled waste. The extra buildings required for the TRU-waste disposal will not be so numerous as those in the complete WIPP reference plan because many of the WIPP buildings--the administrative buildings, for example--will not need to be duplicated. Furthermore, the designs for the reference repository include provision for remote handling that will not need to be duplicated in the extensive HLW-handling areas. The expanded repositories will require an extra shaft for moving TRU waste underground.

The extra underground excavation required for emplacement of TRU waste will be extensive--approximately the entire 3 million tons of salt proposed in the reference design. The preliminary excavation estimate for an HLW repository in a Gulf interior salt dome calls for the removal of 10 million tons of salt. The excavation for TRU waste, to be performed on a second level in the dome, would therefore add about 30% to the excavation for HLW emplacement. A similar increase would be needed at a repository in the Delaware basin.

No site-specific estimates have been made for the HLW excavation in basalt. Because heat-producing waste can be emplaced more densely in basalt than in salt, it might be expected that the total volume to be mined would be smaller. The basalt repository assumed in the GEIS will hold more waste than the salt repository and will operate longer; for this reason the GEIS predicts that 90 million tons of basalt will be removed. The addition of TRU-waste disposal would add roughly 3% to the mined weight, or about 4% to the mined volume, since basalt is roughly 20% more dense than salt. There would be no separate level for the disposal of TRU waste, which would be emplaced on the same level with high-level waste; bringing TRU waste to the repository would therefore require horizontal expansion of the single HLW level assumed in preliminary plans for a basalt repository.

Table 3-11. Local Impacts of Alternative 4: Changes in Predicted Impacts at an HLW Repository Because of the Addition of TRU-Waste Disposal

Impact	Change	
	At HLW repository in salt[a]	At HLW repository in basalt at Hanford
Physical impacts		
Land use, excluding rights-of-way	Increase of less than 25% (50 acres)	Increase of less than 25% (50 acres)
Use of resources		
Construction materials	Increase of perhaps 20-40%	Increase of less than 20%
Water and electricity	Substantial increase: perhaps 70%	Substantial increase: perhaps 50%
Liquid fossil fuels	Increase of less than 10%	Increase of about 1%
Effluents	Small increase: 3-10%	Small increase: 3-10%
Mined-rock pile	Significant size increase: 30%	Slight size increase
Conflict with mineral resources	No conflict in Gulf interior region; no additional conflict in Delaware basin	Probably no conflict
Socioeconomic impacts		
Construction costs	Small increase: 10%	Small increase: 4%
Operating costs	Possible increase as large as 50%	Small increase: less than 10%
Work force	Increase of perhaps 35%	Increase of perhaps 27%
Population changes and service demands	Increase probably not a significant impact on resources of area	Increase probably not a significant impact on resources of area
Transportation impacts		
Radiation doses from normal transportation	Little change	Little change
Radiation doses from accidents	No change that would have effects comparable to those of natural background radiation	No change that would have effects comparable to those of natural background radiation
Impacts during operation		
Radiation doses to regional population	Little change	Little change
Radiation doses from accidents	No change that would have effects comparable to those of natural background radiation	No change that would have effects comparable to those of natural background radiation
Possible long-term impacts		
Possibilities for breach of repository	Scenarios similar to those at WIPP; site selection will insure no increase in predicted risk	Scenarios different from those at WIPP; site selection will insure no increase in predicted risk

[a]Dome salt in the Gulf interior region or bedded salt in the Delaware basin.

Table 3-12. National Impact of Alternative 4: Differences Between the Impact of an Expanded HLW Repository and the Combined Impacts of Separate Repositories for HLW and for TRU Waste

Impact	Difference	
	Expanded HLW repository in salt[a]	Expanded HLW repository in basalt at Hanford
Physical impacts		
Land use, excluding rights-of-way	Decrease of about 40%	Decrease of about 40%
Use of resources		
Construction materials	Decrease of perhaps 20-25%	Decrease of perhaps 10-15%
Water and electricity	Decrease of perhaps 30%	Decrease of perhaps 30%
Liquid fossil fuels	Decrease of less than 1%	Decrease of less than 1%
Effluents	Little difference	Little difference
Mined-rock pile	No difference in total volume	No difference in total volume
Conflict with mineral resources	In Gulf interior region, removal of conflict; in Delaware basin, no difference in conflict	Removal of conflict
Socioeconomic impacts		
Construction costs	Small decrease: perhaps 10%	Small decrease: perhaps 4%
Operating costs	Decrease: perhaps 25%	Decrease: perhaps 10%
Work force	Decrease: about 10%	Decrease: about 10%
Population changes and service demands	Little difference	Little difference
Transportation impacts		
Radiation doses from normal transportation	Predicted small increase: 2 man-rem over several million people	Predicted small decrease: 3 man-rem over several million people
Radiation doses from accidents	No difference that would have effects comparable to those of natural background radiation	No difference that would have effects comparable to those of natural background radiation
Impacts during operation		
Radiation doses to regional population	No difference	No difference
Radiation doses from accidents	No difference	No difference
Possible long-term impacts		
Possibilities for breach of repository	Site selection will insure no increase in predicted risk	Site selection will insure no increase in predicted risk

[a]Dome salt in the Gulf interior region or bedded salt in the Delaware basin.

Physical impacts

The GEIS assumes that land preempted for surface facilities, not including rights-of-way, will total about 200 acres at an HLW repository. Although the comparable area at the WIPP reference site is also about 200 acres (Section 9.1.1.1), the total addition to the HLW repository would probably not exceed 50 acres because most of the WIPP land uses listed in Section 9.1.1.1 would not have to be duplicated. The local increase in land use at the HLW-repository site would be less than 25%. Since alternative 4 would use no land at the reference site, on the national scale the land used under alternative 4 would decrease by about 40% from the land used by the separate HLW and TRU-waste repositories.

The resources used in building the expanded repository for HLW and TRU waste would not be greatly increased over those used for the HLW repository alone. The amounts of construction materials needed depend sensitively on details of the plant design. The GEIS predicts, for example, steel use of 19,000 tons for the reference HLW repository in salt and 43,000 tons for the repository in basalt; the comparable figure for the WIPP reference repository is 15,000 tons, only a fraction of which will be required at the expanded repository. If this fraction is roughly 0.5, the local increase in steel use would be about 40% at the dome-salt repository and less than 20% at the basalt repository; the local increases in the use of copper (20% and 10%) and lumber (25% and 10%) would be smaller. On the national scale the impacts of resource use in construction would decrease; the decreases would range from 20% to 25% in salt and from 10% to 15% in basalt.

Resources to be used in operating the reference repository are comparable to those expected to be used at the HLW repositories. The GEIS predicts electrical power demands of 13,000 and 15,000 kilowatts at the salt and basalt repositories; the reference-repository estimate of 20,000 kilowatts suggests that the use of electrical power at the expanded repository might be substantially increased over the GEIS estimates--perhaps by 50%. Similarly, water use at the reference repository, estimated at roughly 6.5 million gallons per year, is comparable to the uses predicted by the GEIS: 4.5 and 6.4 million gallons per year. On the other hand, the annual use of liquid fossil fuels at the reference repository (200,000 gallons) will be so much lower than the use at the HLW repositories (7.4 and 8.4 million gallons) that the incremental impact of TRU-waste disposal will be negligible. The entries in Tables 3-11 and 3-12 assume that half of the predicted reference-repository use of resources would occur at the expanded repository.

The amounts of effluents released during operation of the WIPP reference repository will be small compared to those released from the HLW-repository operation in salt and basalt. The GEIS predictions for the release of hydrocarbons, for example, are 94 and 100 tons per year; the WIPP prediction is only 3 tons per year. The GEIS predictions for particulate emissions are 41 and 40 tons per year; the WIPP prediction is only 3 tons per year. An expanded repository would accordingly produce only slightly more effluents than an HLW repository, and little decrease in national impacts would result from alternative 4.

The mined-rock pile will be larger at an expanded repository for both types of waste than at an HLW repository. As explained above, about 30% more rock would be mined if TRU-waste disposal is added to an HLW repository in

salt. In the Gulf interior region, however, the mined rock not needed for backfilling will be treated differently from the mined rock at the WIPP: in the humid climate near the Gulf of Mexico measures must be taken to contain the pile, which would otherwise wash onto the surrounding land. At Hanford, which has a dry climate, the basalt pile can probably be left standing at the surface; at an expanded repository there the pile will be only slightly larger than the pile predicted by the GEIS, which is much larger than the pile predicted for the HLW repository in salt.

Conflict with mineral resources would not be an impact of the expanded repositories in salt domes or basalt. Although hydrocarbon resources are sometimes found near salt domes, none exist within or beneath the domes themselves. No mineral resources are thought to exist beneath the basalt layers at Hanford, although further exploration would be required to establish this expectation rigorously. The conflict with mineral resources beneath the WIPP reference site would continue at an expanded repository in the Delaware basin.

Socioeconomic impacts

The socioeconomic impacts of adding TRU-waste disposal to an HLW repository stem from the addition of expenditures for construction and operation and from the creation of additional jobs.

The GEIS estimates construction costs of $1000 million and $3100 million for HLW repositories in salt and basalt, respectively; the WIPP construction cost is $225 million. If roughly half of the WIPP costs were to be incurred in the additions to an HLW repository, the local increase in construction costs would amount to about 10% and 4% in salt and basalt, respectively; the national cost reductions would be about the same percentages. The changes in impacts arising from construction costs would therefore be barely appreciable.

The GEIS estimates operating costs for a salt repository at $590 million over 15 years and for a basalt repository at $2390 million over 24 years. The corresponding cost for the WIPP reference repository, over 24 years, would be $864 million. To predict the operating cost of an expanded repository for HLW and TRU waste would require a careful estimate of the fraction of the WIPP cost to be added to the HLW-repository cost. In the absence of designs for an expanded repository, this prediction is difficult to make. Since the operating costs of separate repositories in salt are roughly similar, the operation of the expanded repository in salt might be as much as 1.5 times as costly as the operation of an HLW repository there. At a basalt site the added cost of operation would probably be less than 10%. Under these assumptions, the national reductions in operating costs might be 25% and 10% in salt and basalt, respectively.

A prediction of the work force at an HLW repository is uncertain because the plant designs are still in early stages. The GEIS predicts 870 employees at an HLW repository in salt; other estimates range from 1000 to 1500. The GEIS predicts 1100 employees at an HLW repository in basalt. Of the 444 employees predicted for WIPP operation, probably all the miners (109) and storage workers (49) would be needed at an expanded repository; an undetermined number of the 286 employees at the surface would also be needed. Under the assumption that about 150 of these WIPP surface workers would be needed, the number of jobs added to an HLW repository would be about 300, an addition of 35% at a salt repository and 27% at a basalt repository. The national reductions in work force would be about 10% at either repository.

These increases in the work force would increase the socioeconomic impacts predicted for the HLW repositories. The GEIS predicts these impacts in terms of the number of people expected to move into the area around a repository and in terms of the increased demands for social services. It also accounts for the variations that occur in these impacts because the sites are in different areas of the United States. For example, the impacts are generally smaller at sites in the southeast than in the southwest; for this reason the socioeconomic impacts of the WIPP reference repository cannot be added directly to those of the dome-salt repository. Since none of the socioeconomic impacts predicted by the GEIS are likely to strain the resources of the areas near the repositories, the addition of TRU-waste disposal to HLW repositories would not severely affect those areas, and the national impacts would change little.

Transportation impacts

The added impacts of transporting TRU waste to an HLW repository have been predicted by calculations of the population dose commitments that would result from shipping defense TRU waste to the Gulf interior region and to Hanford. Performed by the methods used in Section 6.6 to analyze normal transportation, these calculations predict dose commitments of 15, 17, and 12 man-rem for the transportation of TRU waste to the Delaware basin, to the Gulf interior region, and to Hanford, respectively. According to these figures, the impacts of transportation would, in principle, increase in the Gulf interior region and decrease at Hanford; the smaller impact of transportation to Hanford is due primarily to the short distance between Hanford and the INEL, the primary source of TRU waste. On a national scale, the population dose commitments could be reduced by placing an expanded repository at Hanford; they would be increased by carrying the INEL waste to the Gulf interior region instead of the Delaware basin. Since all these population dose commitments are spread over several million people, there would be little change in transportation impacts, either locally or nationally, if alternative 4 is selected.

Because the addition of TRU-waste disposal will require an increased number of shipments, the probabilities of transportation accidents on the way to the expanded repository would be greater than the probabilities associated with transportation to an HLW repository. The analysis of accidents carried out in Section 6.7 shows, however, that the conceivable accidents with TRU waste would produce effects that are small in comparison to the effects of natural background radiation.

Impacts during plant operation

The GEIS predicts that emissions of radioactivity from an HLW repository, whether in salt or in basalt, will be such that the 70-year dose commitment to a regional population will be less than 100 man-rem, which is far below the doses received by the regional population from natural-background sources. Since the corresponding dose commitments from the WIPP operation are much smaller than 100 man-rem, adding TRU-waste disposal to an HLW repository would add little to the impacts of routine operation. Since the same amounts of material will be handled in the expanded repository as in separate repositories, alternative 4 will offer no change in routine emissions on a national scale.

The consequences of accidents at an expanded repository for HLW and TRU waste would be dominated by the consequences of dropping a spent-fuel

canister--the same accident identified as the most severe at the WIPP and at the HLW repositories examined in the GEIS. Adding TRU-waste disposal to an HLW repository would not make possible any additional accidents of greater severity than those already possible there. Handling the TRU-waste packages would increase the probability of an accident with waste of lower activity than spent fuel; as pointed out in Table 3-7, however, the population dose commitments from such accidents are much smaller than those from natural background radiation.

Possible long-term impacts

As at the WIPP or at an HLW repository, no long-term release of radioactive material is expected at an expanded repository. Analyses of the consequences of hypothetical releases are nevertheless under way; using methods similar to those of Section 9.5.1, these studies will postulate scenarios and determine their consequences.

The scenarios for release from salt domes in the Gulf interior region will probably be similar to those postulated in the WIPP studies (Section 9.5.1); most of them will involve intrusion by water that dissolves the salt and carries the waste. Some of the postulated events that breach the repository will be different from the WIPP events because of differences in the geologic and hydrologic characteristics of salt domes and salt beds. The drilling scenarios assumed in the WIPP analyses will be less likely in dome salt.

The scenarios for release from Hanford basalt will be much different from the WIPP scenarios. Because basalt is practically insoluble, the postulated water-intrusion events will involve different flow patterns; the forces driving the water are likely to arise from different sources. Effects of glaciers, for example, will appear in these scenarios; flow along existing joints can be postulated in basalt but not in salt. Direct drilling into a basalt repository is even more unlikely than drilling into a salt repository.

Although the conceivable mechanisms for breaching a repository are clearly different among the bedded-salt, dome-salt, and basalt sites, there is at present no evidence that any of the sites is safer than the others. Although each site has characteristics that could conceivably give rise to a breach of a repository in the far-distant future, the probability is low that such a breach could produce hazardous releases of radioactive material.

In the analysis of long-term impacts at the reference repository, the releases from spent fuel have much more severe effects than the releases from TRU waste (Table 3-7 and Section 9.5.1). At an expanded repository for both types of waste this domination by spent fuel will be much greater; adding TRU-waste disposal to an HLW repository would barely increase the effects of long-term release. More important, no site will be selected if it appears to offer significant risks from long-term releases.

Summary

Adding TRU-waste disposal to an HLW repository in a Delaware basin salt bed, a Gulf interior region salt dome, or basalt at Hanford would slightly increase the local environmental impacts of the HLW repository. The local physical impacts would increase by fractions of the original impacts, probably

no more than 50% and, for most of the impacts, much less. The local socioeconomic effects might increase appreciably around the salt-dome site because the expenditures for TRU-waste disposal might be a significant fraction of the costs of HLW disposal there; at a basalt site, where operating costs are higher, the added impacts would probably be insignificant. The predicted impacts from the transportation of TRU waste to a salt dome are barely larger than the impacts from transportation to the WIPP reference repository; impacts of transportation to Hanford are barely smaller. Neither set of impacts is, however, comparable to the impact of natural background radiation. Releases of radioactivity during repository operations with TRU waste are small; they would not be a significant addition to the small releases from an HLW repository. There is no reason to expect that adding TRU waste to an HLW repository at either site would appreciably increase the probability of long-term releases of radioactive material.

On a national scale, emplacing TRU-waste at an expanded HLW repository would decrease some of the impacts of operating separate HLW and TRU-waste repositories. The physical impacts would be reduced by amounts ranging up to 40%. The predicted socioeconomic impacts would decrease if the expanded repository is built in either salt or basalt. The impacts of transportation would be greater if the expanded repository site is in salt than if it is in basalt; the difference would, however, produce effects far smaller than those of natural background radiation. On a national level, there would be no difference in impacts from repository operation or, probably, from unexpected long-term releases of radioactivity.

3.5 ALTERNATIVES 5 and 6: TRU-WASTE REPOSITORY BUILT AFTER THE CHARACTERIZATION OF ADDITIONAL SITES, WITH AND WITHOUT AN ISF

If the decision to build a TRU-waste repository is deferred until approximately 1982, additional sites will have been investigated. If these sites are suitable, it will then be possible in principle to choose a site from the Delaware basin or some other part of the Permian basin, the Gulf interior region, and Hanford. It will also still be possible to choose whether to build an ISF in the TRU-waste repository. This section predicts the environmental impacts of a repository in these places. The differences in impacts with and without an ISF are small and similar to the differences in impacts between alternatives 2 and 3. A full discussion of impacts at a site in the Delaware basin is not needed here, because they are discussed in Sections 3.2 and 3.3; selecting a Delaware basin site in 1982 would simply delay the onset of the impacts. Effects of this delay are discussed in Section 3.5.1. Section 3.5.2 discusses the impacts of TRU-waste repositories in dome salt and in basalt.

3.5.1 Impacts of Delaying the WIPP Reference Repository

The environmental impacts discussed in Sections 3.2 and 3.3 are largely independent of the time when construction of the WIPP begins. The issues involved in delay are primarily other than environmental.

Delay of a project can be environmentally helpful if the time gained can be used to decrease the environmental impacts of the project; delay in the WIPP program, however, is not likely to reduce the impacts. Studies at the WIPP reference site will continue as needed whether or not the project is delayed, but the supplemental information these studies will provide is not expected to change the predicted impacts and risks significantly. Rather, this information will improve confidence in the risk predictions and narrow the uncertainties in them. Bounding calculations using the existing data are already sufficient to evaluate the potential impacts of the WIPP reference repository.

If the WIPP were delayed, the amount of defense TRU waste would increase by about 10% per year at current generation rates, with corresponding increases in the costs and environmental risks of the current temporary storage methods. The spent fuel that would have been emplaced in the ISF would continue to occupy space in storage pools throughout the delay period.

A major impact of delaying the WIPP would be the cost of closing out the current project and then reopening it several years later. To end the current programs would require carefully compiling, cataloging, and storing for future use all the documents already developed; negotiating and paying contractors' fees; and reimbursing contractors for the costs they will incur in terminating the programs. The total close-out cost is estimated at $3.2 million.

After a delay of roughly 4 years, the costs of designing and building the WIPP reference repository will have increased. All the currently estimated costs will increase because of inflation, which can be estimated at 8% per year. This increase will affect the cost of design, development of special waste-handling equipment, and construction of the plant. Moreover, restarting the design will require funds for assembling a new design team; it will also be necessary for this new team to review the earlier design work and revise it according to whatever new standards and methods have become applicable since the closing of the project. After the addition of a 25% contingency allowance to cover any other possibilities, the estimated cost of restarting the project amounts to an increase of nearly $280 million (including the $3.2 million close-out cost) over currently estimated costs.

Two alternatives have been considered for delay in removing TRU waste from places where it is now stored: delaying retrieval from storage pads until it is to be moved or retrieving it now and putting it into better storage. The effects of these alternatives have been shown to be minimal. Even a 20-year delay would cause virtually no change in the environmental effects and radiological risks associated with retrieving, processing, and shipping TRU waste to the WIPP or another Federal repository. The radiological effects would be much less than those from natural background radiation (Section 9.6). The nonradiological effects would generally be limited to those associated with a commitment of manpower and the use of other resources.

Degradation of the waste containers at INEL could occur if retrieval were delayed for 20 years, but no release of radionuclides to the environment would be expected. Leaving the waste in Idaho for 20 years would slightly increase the probability of release of radionuclides as a result of an improbable natural disaster. The risk, however, is small compared with that from natural background radiation.

Of the two delay alternatives considered for the INEL, delaying retrieval would cost an estimated $6.4 million less than retrieving and processing immediately. However, the cost savings would be only about 3% of the total cost of removing the waste from Idaho. The radiological risk from delaying retrieval for 20 years is negligibly larger than the risk from retrieving the waste, processing it, and then storing it at the INEL site for 20 years; maintenance and surveillance will be required even if the waste is left in place, as is.

3.5.2 Impacts of TRU-Waste Repositories

If a TRU-waste repository is built in bedded salt in the Permian basin, in a salt dome in the Gulf interior region, or in basalt at Hanford, the general design of the plant will remain nearly the same as the WIPP reference design. The rates of receipt of waste and the handling methods will change little, if at all. The predicted environmental impacts will also change little; the changes will result mostly from differences in rock types, surrounding areas, and transportation routes.

Because no conceptual designs exist for TRU-waste repositories in dome salt and basalt, predictions of the changes in impacts must be qualitative. Table 3-13 compares the impacts of TRU repositories at the alternative sites with the impacts of the reference repository (Section 3.2). Because the two alternative repositories in salt will exert similar impacts, Table 3-13 presents their impacts in only one column and notes differences where they are appreciable. The remainder of this section explains the entries in Table 3-13.

As pointed out in Section 3.3, deleting the ISF from the WIPP mission produces few significant changes in the predicted environmental impacts. Instead of presenting separate discussions covering inclusion and omission of the ISF, this section simply notes impacts that would be changed by the ISF.

Physical impacts

Because the plant design and the operating methods will probably remain the same, a TRU-waste repository in a salt dome or in basalt will exert nearly the same physical impacts as a TRU-waste repository in bedded salt. The principal differences would appear in the effects of the mined-rock pile and in the conflict with mineral resources.

Although the mined-rock pile would be the same size at both sites in salt, the humid climate in the Gulf interior region could change its impacts. The impacts of the WIPP pile in the Delaware basin are expected to be small (Section 9.1.3), principally because of the dry climate there. In theory, heavier rainfall could wash the mined rock onto surrounding land. Preliminary plans for an HLW repository in the Gulf interior region involve special precautions to contain the pile; moreover, it is likely that the salt not needed for backfilling will be removed from the site. These measures will probably hold the impacts of the mined rock to the low estimates made for the Delaware basin site.

A basalt mined-rock pile may be slightly smaller because the storage cavities in the competent rock may be mined at a higher extraction ratio, with

Table 3-13. Changes in Predicted Reference-Case Impacts if a TRU-Waste Repository Is Built in Salt or Basalt

Impact	Change	
	Repository in salt[a]	Repository in basalt at Hanford
Physical impacts		
Land use	No change	No change
Resources used	No change	No change
Effluents	No change	No change
Mined-rock pile	No size change; extra measures necessary to contain pile in Gulf interior region	Possible small decrease in size; little possibility of contaminating land
Conflict with mineral resources	Reduced to zero in Gulf interior region; perhaps zero in Permian basin, depending on site	Probably reduced to zero
Socioeconomic impacts		
Construction costs	No change	Increase
Operating costs	No change	Increase
Work force	No change	Little change
Population changes and service demands	Significant decrease in Gulf interior region; little change in Permian basin, depending on site	Significant decrease
Transportation impacts		
Radiation doses from normal transportation	In Gulf interior region, 12% increase with ISF, 13% increase without ISF; little change in Permian basin	6% decrease with ISF, 20% decrease without ISF
Radiation doses from accidents	No change	No change
Impacts during operation		
Routine radiation doses to population	Increase in Gulf interior region because of larger surrounding population; little change in Permian basin; no change in maximum doses	Increase because of larger surrounding population; no change in maximum doses
Radiation doses from accidents	Same as for routine doses	Same as for routine doses
Possible long-term impacts		
Possibilities for breach of repository	Scenarios similar to those at WIPP; site selection will insure no increase in predicted risk	Scenarios different from those at WIPP; site selection will insure no increase in predicted risk

[a]Dome salt in the Gulf interior region or bedded salt in the Permian basin.

less necessity for numerous corridors. Furthermore, a basalt pile is not expected to be as damaging to surrounding land as a salt pile might be, especially in the arid climate of Hanford.

Conflict with mineral resources is one of the principal impacts of a repository in the Delaware basin. A repository elsewhere in the Permian basin might or might not exert this impact, depending on the specific site. A repository in dome salt, which overlies no valuable mineral deposits, would not exert this impact. Although it is not completely certain that no mineral deposits lie beneath the Hanford basalt layer, no evidence has suggested they are present.

Socioeconomic impacts

The impacts resulting from expenditures for construction and operation would change little if the WIPP reference mission is accomplished at the alternative sites. These costs would be greater at Hanford because mining hard rock is more expensive than mining salt; a reliable prediction of the difference in cost would require a conceptual design for a TRU-waste repository there.

The size of the work force would probably not change unless the increased difficulty of mining basalt requires a significantly larger group of miners at Hanford. The population changes and demands for additional services will be smaller than those in the Delaware or Permian basins because of the larger work force and increased social services already available in the Gulf interior region and at Hanford.

Transportation impacts

The impacts of transporting TRU waste to the alternative sites have been evaluated through calculations of population dose commitments. Performed by the methods used in Section 6.6 to analyze normal transportation, these calculations predict dose commitments of 17, 19, and 16 man-rem for the transportation of TRU waste and spent fuel for an ISF to the Delaware basin (assumed to represent the Permian basin), to the Gulf interior region, and to Hanford, respectively. If the spent fuel is not shipped, these three dose commitments are 15, 17, and 12 man-rem. Since all three dose commitments are small, there would be little change in the transportation impacts summarized in Sections 3.2 and 3.3.

The analyses of transportation accidents in Section 6.7 remain valid for alternatives 5 and 6 because the same materials would be shipped in the same types of containers.

Impacts during operation

The normal release of radioactivity during routine plant operations would remain unchanged if the plant is built at one of the alternative sites. The maximum dose commitments received by persons near the plant would also remain the same. The total population dose commitment, expressed in man-rem, would increase because the population densities in the Gulf interior region and near Hanford are greater than the density in the Delaware basin. Because the dose commitments will remain much smaller than those from natural background radiation, the predicted effects of routine plant operation would change little.

The accidents postulated at the repository would remain the same at any of the alternative sites. Except for delivering doses to the larger population, their consequences would also remain unchanged, and no impacts comparable to those of natural background radiation would be expected.

Possible long-term impacts

As explained in Section 3.4, the scenarios for breaching a decommissioned repository in the distant future will differ among the alternative sites, which have significantly different geologic and hydrologic characteristics. Development of these scenarios is now under way. The scenarios for breaching a dome-salt repository will probably resemble those at the reference site; the scenarios for breaching a basalt scenario are likely to be much different. Until these scenarios are completed and detailed analyses are carried out, no rigorous comparison of the long-term impacts of TRU-waste repositories at the alternative sites can be made. Studies to date, however, have shown no reason to expect that any of the sites is clearly safer than the others. No long-term releases are expected from a TRU-waste repository, whether spent fuel is emplaced there or not.

Summary

The environmental impacts of a TRU repository at the alternative sites would be nearly the same as the impacts of a TRU repository in the Delaware basin. The principal differences in the predicted impacts are due to the different mined-rock piles, to the absence of valuable mineral resources at the alternative sites, and to the different socioeconomic conditions prevailing in the alternative regions.

3.6 ALTERNATIVE 7: DISPOSAL OF TRU WASTE IN AN HLW REPOSITORY SELECTED AFTER THE SITE-QUALIFICATION PROGRAM IS COMPLETED

If selection of a repository site is deferred until 1985, it may be possible to choose the location from an extensive array of investigated sites in different geologic media. By 1985 studies in shale and tuff, in addition to further studies in bedded and dome salt, may have shown that sites not considered in Sections 3.1 through 3.5 are also suitable for the disposal of TRU waste.

Impacts

The environmental impacts of repositories holding both HLW and TRU waste in bedded or dome salt and in basalt are treated in Section 3.4. If a site is selected in the Delaware basin, in the Gulf interior region, or at the Hanford Site, its impacts will be those already presented except for the minor influence of delay, discussed in Section 3.5.1. If a site is selected in salt or basalt at some location other than these three, its impacts are likely to be similar; the principal modifications would probably arise from differences in climatic conditions affecting the mined rock stored at the site, from differences in conflicts with mineral resources lying beneath the site, and from differences in socioeconomic conditions around the site. The effects of breaching the repository in the distant future are impacts that may differ

from site to site; they cannot be evaluated, however, until specific sites have been selected. No site will be selected if a repository there can be expected to exert significant long-term impacts.

If a site is selected in shale, granite, or tuff, the impacts are likely to be different. The GEIS (DOE, 1979) analyzes HLW repositories in shale and granite; that analysis, which does not consider specific sites, predicts impacts approximately like those of the salt and basalt repositories. Until further study of shale, granite, and tuff has been carried out and sites have been identified, the impacts of repositories in them cannot be predicted in detail. No analyses performed to date have suggested reasons for rejecting these materials on grounds of unacceptable environmental impacts.

Summary

Few changes would occur in the predicted environmental impacts of a repository in salt or basalt if selection of the site is deferred until an extensive array of sites is available; the effects of delay would dominate the changes. A repository in shale, granite, or tuff would exert different impacts, which can be accurately predicted only after further study of these materials and the selection of specific sites.

3.7 IMPACTS OF A STAND-ALONE INTERMEDIATE-SCALE FACILITY

Chapter 2 discusses and dismisses the possibility of a facility whose only purpose is to be an intermediate-scale facility (ISF) for the storage of spent fuel. Nevertheless, this section outlines the costs and impacts of such a stand-alone ISF, comparing them with those of the WIPP reference repository, since the WIPP analysis (Section 3.2) for the most part distinguishes between the impacts from spent fuel and from TRU waste.

Assumptions

The physical plant for a stand-alone ISF would be smaller than that for the reference repository because there would be no need for such elements as a large waste-handling building, two storage levels, and extensive underground mining. On the other hand, elements such as a shielded hot cell, multiple shafts, an underground area, and shielded transporters would still be required. At the reference site, the stand-alone ISF would use only the lower (2700-foot-depth) of the two storage levels planned for the reference repository. The deeper level would be used because of its purer salt.

Impacts

The physical impacts of a stand-alone ISF would be appreciably smaller than those listed in Table 3-3. The mined-rock pile and the area reserved for underground operations would be much smaller. However, 2-mile buffer zone outside a small repository area would still be required, and the total land committed would be about half that required for the reference repository.

The cost of engineering and construction for the stand-alone ISF is roughly estimated to be half of the $430 million projected for the WIPP reference repository. The work force would be nearly as large as that for the reference repository during construction but smaller during operation.

Four to five years would suffice to load a stand-alone ISF with 1000 spent-fuel assemblies, and only a few hundred shipments would be involved. Table 3-5 indicates that during this period the population exposure along transportation routes would be 2.8 instead of 17.4 man-rem/yr. The consequences of transportation accidents, should they occur, would not be changed.

The radiological impacts of operation would be little reduced from those of the reference repository because normal and accidental releases from spent fuel dominate those from TRU waste.

In the long term, the expected release from a stand-alone ISF is the same as that from the reference repository--namely, zero. The releases predicted for a breach in an ISF would depend on its location; if it is in the Delaware basin, the releases would be similar to those from the reference repository because the radionuclides in the spent fuel dominate releases from the reference site.

Summary

The physical impacts of a stand-alone ISF would be appreciably smaller, often by half, than those of the reference repository. The cost would probably be on the order of $200 million. Risks during normal transportation would be reduced, but the consequences of accidents would not be changed. Radiological risks at the site during the loading period and in the long term would hardly be reduced at all.

REFERENCES FOR CHAPTER 3

DOE (U.S. Department of Energy), 1978. Draft Environmental Impact Statement, Storage of U.S. Spent Power Reactor Fuel, DOE/EIS-0015-D, Washington, D.C.

DOE (U.S. Department of Energy), 1979. Draft Environmental Impact Statement, Management of Commercially Generated Radioactive Waste (in press).

4 Programmatic Impacts of Alternatives

A choice among the waste-management alternatives discussed in Chapter 2 will be guided both by their environmental impacts and by their ability to meet the objectives of the waste-management program. Chapter 3 discusses their impacts on the environment; this chapter discusses their impacts on the overall program. This discussion is in terms of the alternatives* derived in Section 2.4.4:

1. No action

2. The WIPP reference repository

3. The WIPP reference repository without an intermediate-scale facility

4. Disposal of TRU waste in the first available high-level-waste (HLW) repository

5. Delayed and possibly relocated TRU-waste repository with an intermediate-scale facility

6. Delayed and possibly relocated TRU-waste repository without an intermediate-scale facility

7. Disposal of TRU waste in an HLW repository chosen after the entire site-qualification program is complete

The analysis in Chapter 3 shows that the no-action alternative (alternative 1), while exerting only small environmental effects in the short term (decades), is environmentally unacceptable as an option for the permanent disposal of TRU waste. The impacts of the remaining six alternatives (2 through 7), on the other hand, are small in both the near term and the long term (centuries and longer) and are not different enough from each other to afford a basis for choice solely on environmental grounds. The choice must therefore rest largely on programmatic considerations.

In comparing the programmatic advantages and disadvantages of the alternatives, this discussion does not attempt to select a "best" alternative. Rather, this analysis attempts to discover whether some of the alternatives merit stronger consideration than the others because they meet the policy objectives better. In addition, it is hoped that this discussion will stimulate comment and criticism that will benefit the process of choosing among the alternatives.

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*As discussed in Section 2.4.3, the U.S. Department of Energy (DOE) does not consider a stand-alone intermediate-scale facility (ISF) for spent fuel to be an attractive alternative. Nevertheless its environmental impacts are discussed in Section 3.7 in order to comply with the requirements of the National Environmental Policy Act of 1969. Programmatically, a stand-alone ISF is not desirable because it addresses only a small part of the waste-management objectives listed on the next page. It fully satisfies only objective 6 and to a lesser degree objectives 2 and 4.

Seven near-term policy objectives for waste management were derived in Chapter 2:

1. To meet stated U.S. Government intentions for early removal of the TRU waste stored at the Idaho National Engineering Laboratory.

2. To use existing opportunities, if they are adequate and acceptable, to advance waste-management technology and to dispose of existing wastes.

3. To emphasize work at potential sites that may realistically be considered for waste disposal.

4. To proceed by deliberate steps in a technically conservative manner.

5. To build a licensed full-scale TRU-waste repository in advance of HLW repositories, thus gaining experience in designing, analyzing, and operating repositories and in obtaining approval from the NRC and other regulatory bodies.

6. To build a licensed intermediate-scale facility for the disposal of spent fuel from reactors in advance of HLW repositories, thus gaining further experience in designing, analyzing, and operating repositories and in obtaining approval from the NRC and other regulatory bodies.

7. To combine compatible facilities, where suitable, in order to avoid unnecessary costs and to assist in integrating the research-and-development programs.

The remainder of this chapter discusses the extent to which each of alternatives 2 through 7 satisfies these objectives.

Meeting stated intentions

In 1970 the U.S. Atomic Energy Commission placed high priority on removing TRU waste from the Idaho National Engineering Laboratory to a Federal repository (letter, G. T. Seaborg to Senator Frank Church; see DOE, 1979, Appendix A). This intention was restated as recently as March 2, 1978 (DOE, 1979, Appendix A).

Alternatives 2 and 3 meet this intention at the earliest possible opportunity. Alternatives 4 through 7, which postpone the decision to build a repository, allow more TRU waste to accumulate at the Laboratory; thus in addition to the delay in deciding, the removal of waste from Idaho is further delayed by the longer time required to draw down the increased inventory of retrievable TRU waste. The greatest net delay in meeting the intention comes from alternative 7.

Using existing opportunities

The WIPP reference site, because it has already been studied extensively, presents an immediate opportunity to advance waste-management technology through learning, at a real repository, about institutional and operational problems.

Alternatives 2 and 3 seize such an opportunity; of these two, alternative 2 would be more useful because of the colocated intermediate-scale facility for spent fuel. Alternatives 4 through 6 represent a deferral for 3 or more years, and alternative 7 an even further deferral.

Emphasizing work at actual sites

Alternatives 2 through 7 all involve work at sites that can realistically be considered for repositories. They differ primarily in the time they start, as discussed above.

Proceeding by deliberate, conservative steps

In alternatives 2 through 7 there are three decision points about 3 years apart. The largest number of steps could be taken under the earliest decision--to undertake alternatives 2 or 3, which start now and therefore provide the longest period for experimenting with high-level waste and for increasing the understanding of HLW repositories. Alternatives 5 and 6 are similar to alternatives 2 and 3 but accept a starting date 3 or more years later in order to take advantage of additional qualified repository sites (Gulf interior salt domes and Hanford basalt). If a decision cannot be made by 1982, however, then the waste-management program will have lost the chance for a long period of learning before building an HLW repository. Alternatives 4 and 7 meet this objective least well, because they allow for the fewest steps before facing the problems of a repository for both HLW and TRU waste.

Opportunities for gaining experience in a repository for TRU waste and in an intermediate-scale facility for spent fuel should be linked with the strategy for HLW repositories not through such simple terms as "early" and "late" but in terms of a steadily increasing understanding of risks and their mitigation. In this context, a later decision on the siting of the first HLW repository could place a greater value on an early TRU-waste repository with an intermediate-scale facility; such a repository would be a valuable first step in a program of operational-risk assessment. The longer the delay in the decision on an HLW repository, the greater would be the value of the growing body of operational experience from the earlier repository.

Premature steps in the development of the technology could, on the other hand, lead to operational failures. This thought does not argue so much against an early decision as in favor of making the early decisions carefully and conservatively.

Obtaining early experience

The issues in the long-term isolation of transuranic nuclides are similar for TRU waste and for high-level waste. For this reason a TRU-waste repository can provide partial tests of the licensing process for a later HLW repository. The early problems in licensing a TRU-waste repository will require careful handling so that approaches to HLW-repository site selection, design, and operation can derive maximum benefit from the earlier experience.

Similarly, licensing the intermediate-scale facility can provide experience in the regulatory processes required for high-heat waste; this experience

can benefit (but not substitute for) later licensing decisions respecting high-level waste. Sufficiently early experiments with high-level waste in a TRU-waste repository with an intermediate-scale facility can provide a continually increasing body of data beneficial to later decisions.

Only alternatives 2, 3, 5, and 6 achieve the objective of obtaining early technical and institutional experience. Alternatives 2 and 3 would give useful experience earlier, although they raise concerns about adequate preparation; they also give a longer period of time for analyzing this experience before the next major decision is made. Thus, alternatives 2 and 3 maximize the lead time; 5 and 6 still provide some lead time; 4 and 7 do not meet this objective at all.

The relationships among institutions involved in waste disposal span a great range of possible issues and interests (IRG, 1979, p. 87ff). These relationships can obviously be exercised earliest and over the longest period of time under alternative 2, the reference case. Alternative 3 may be perceived as a less complex basis for early cooperation and negotiation, particularly if there is significant state and local sensitivity or uncertainty about an associated intermediate-scale facility or the additional transportation risks it entails. If the public were not satisfied with respect to these matters, an alternative 2 or 3 might be delayed and become an alternative 5 or 6. On the other hand, the greater the local sensitivities and uncertainties, the more important it is to address them early and the greater the risk in doing so.

The development of waste-management technology will obviously benefit from a generous lead time and from the existence of an operating test bed. Repository-model validation, engineering specifications, construction techniques, monitoring requirements, waste processing and containerization, transportation systems, and other technical areas require feed-back information from the development of a specific site and the handling of waste in operational quantities. The long-term planning for nuclear-waste management depends on a mature technical foundation derived from operating experience.

Many of the technical developments are likely to be profoundly influenced by the choice of geologic medium. If, for example, an HLW repository is to be sited in basalt, early emphasis on a bedded-salt repository for TRU waste or spent fuel might only weakly enhance, or perhaps even impede, the development of supporting technology for a basalt site. This possibility would favor alternatives 4, 5, and 6 because in 1982 a wider choice of geologic media and locations is likely to be available.

In summary, one central programmatic issue of the decision appears to be the tradeoff between the values of gaining early experience and the risks of proceeding prematurely.

Combining compatible facilities

Two different combinations are involved. Alternatives 2 and 5 combine a TRU-waste repository and an intermediate-scale facility for spent fuel; alternatives 4 and 7 accommodate TRU waste and high-level waste in the same mined repository. The first type of combination occurs early, before commitment to a decision about high-level waste; the latter is a decision about high-level waste.

The only clear conclusion here is that alternatives 3 and 6, which provide no combination whatsoever, are the least favorable with respect to this objective.

Summary

The analysis developed in this chapter suggests the following tabular comparison of alternatives:

Objective	Best alternatives	Worst alternatives
Stated intentions	2, 3	7
Existing opportunities	2, 3	7
Work at actual sites	No distinction	
Deliberate steps	2, 3 or 5, 6	4, 7
Early experience with TRU waste	2, 3	4, 7
Early experience with ISF	2, 5	3, 4, 6, 7
Combination of facilities	2, 4, 5, 7	3, 6

This summary suggests that alternatives 2, 3, and 5 merit the most favorable consideration among all the alternatives evaluated.

REFERENCES FOR CHAPTER 4

DOE (U.S. Department of Energy), 1979. Environmental and Other Evaluations of Alternatives for Long-Term Management of Stored INEL Transuranic Waste, DOE/ET-0081, Washington, D.C.

IRG, 1979. Report to the President by the Interagency Review Group on Nuclear Waste Management, TID-29442, U.S. Department of Energy, Washington, D.C.

5 Waste Forms

This chapter describes the interim criteria for accepting the wastes that will be stored at the WIPP reference repository and describes processing that might be required for TRU waste if certain waste forms are not permitted. Detailed descriptions of the various waste types are given in Appendix E.

5.1 WASTE-ACCEPTANCE CRITERIA

In 1977, The U.S. Department of Energy (DOE) formed the Waste Acceptance Criteria Steering Committee (WACSC). The Committee initially consisted of technical personnel from DOE headquarters, DOE field offices controlling defense wastes, the Office of Waste Isolation, and the WIPP staff from Sandia Laboratories. The Committee has since been expanded to include representatives from the Rocky Flats Plant (DOE's largest producer of defense TRU waste), the Office of Nuclear Waste Isolation,* and the Westinghouse Electric Corporation (the WIPP technical-support contractor).

The WACSC reconciles the interests of various agencies involved with the production, treatment, and disposal of defense TRU wastes. Its ultimate goal is to formulate workable, practical criteria for the acceptance of these wastes. Data for quantifying the criteria are being developed in research-and-development programs at various DOE laboratories. The criteria are constantly evolving and, as described below, reflect only interim proposals. They are continually subject to revision; only after the WIPP design has been made more nearly final and TRU-waste performance data have been gathered will a final acceptance-criteria document be prepared. The target date for publishing the document is July 1979.

5.1.1 Definitions

Discussions of waste-acceptance criteria frequently use several terms that need to be clearly defined: container, package, overpack, combustible material, gas-producing material, and immobilized material. Each is defined below according to its accepted meaning in this chapter. These are not official definitions, as precisely described in the proposed WACSC Waste-Acceptance Criteria. Rather, they are abstracted versions of the official definitions; they convey concepts and avoid specific detail.

Container: A drum, box, or canister that immediately surrounds the waste is the waste container. Any associated hardware such as liner material or spiders for spacing is considered part of the container.

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*The Office of Waste Isolation (OWI) was set up by the Union Carbide Corporation, Nuclear Division, under contract with DOE to manage part of the National Terminal Waste Storage Program. On July 1, 1978, the responsibilities of the OWI were transferred to the newly created Office of Nuclear Waste Isolation, under the management of the Battelle Memorial Institute, Columbus, Ohio.

Package: Once waste is placed inside the container, the container becomes an integral part of the waste. The waste and its container are called the waste package. It is the package that is emplaced in the repository.

Overpack: If required by the physical condition of the container or by the surface-contamination levels, a supplementary layer of containment is placed over the original container and is then considered to be part of the waste package. The supplementary containment is the overpack.

Combustible material: Any material that will sustain combustion in air at a temperature of 1475°F for a period of 5 minutes is combustible.

Gas-producing material: Any material that produces gas during its decomposition is gas-producing. Many materials, particularly organic materials, produce hydrogen, methane, carbon monoxide, and carbon dioxide by radiolytic decomposition, pyrolysis, chemical reaction (corrosion), and/or bacterial decomposition. The salt formation at the reference site has a very low permeability for these gases, and the potential may exist for producing gas pressures high enough to disrupt the rock formations immediately surrounding the repository. The rates of gas production by the various mechanisms and the permeability of the salt formation are now being studied.

Immobilized material: Any material, excluding liquids, that contains less than 1% (by weight) of powder (less than or equal to 10 microns in size) is considered immobilized. The intent of immobilization is to minimize the amount of respirable material in the waste packages.

5.1.2 Transuranic Waste

Transuranic waste is categorized in two classes: contact-handled (CH) and remotely handled (RH). A qualitative distinction between contact-handled and remotely handled TRU waste is made in this document: contact-handled waste emits so little radiation that workers can handle it without extensive shielding; remotely handled waste requires shielding and/or remote handling to protect operating personnel. Therefore, contact-handled TRU waste is distinguished from remotely handled TRU waste on the basis of the surface-dose rate. A criterion endorsed by the WACSC designates waste packages with surface-dose rates no higher than 200 millirem per hour (mrem/hr) as contact-handled TRU waste and those with surface-dose rates higher than 200 mrem/hr as remotely handled TRU waste.

Contact-handled TRU waste

About 98% (by volume) of the TRU waste produced in the DOE complex is classified as CH TRU waste.

Contact-handled TRU waste exists in a wide variety of physical forms, ranging from unprocessed general trash and concrete-stabilized sludge to decommissioned machine tools and glove boxes. Most of the pre-1970 (buried) waste is in 55-gallon drums. Although drums are still widely used, the present trend is toward large plywood and metal boxes, which not only cost less than drums but also make more efficient use of storage volume. At

present, about 70% of all CH TRU waste is put into boxes, most of it in special plywood boxes, about 4 by 4 by 7 feet in outside dimensions, that are covered with a 3-millimeter layer of fiberglass-reinforced polyester and lined with polyvinyl chloride and fiberboard. These boxes are approved by the U.S. Department of Transportation and are known as DOT-7A containers.

A typical plywood box contains 13 grams of plutonium isotopes and produces a thermal output of about 0.03 watt; a typical drum contains 8 grams of plutonium and produces about 0.02 watt. Surface-dose rates for drums and boxes are very low: approximately 3 mrem/hr on the average for drums and 1.4 mrem/hr on the average for plywood boxes (Shefelbine, 1978).

The details of the CH TRU waste-acceptance criteria and the rationale for them are still being developed by WACSC. The criteria cover many aspects of waste form, container design, and package design; the present interim criteria are described below. Details of these interim criteria governing waste forms, containers, and packages are found in Table 5-1.

Several proposed criteria restrict the form of the waste. For obvious reasons, and with no serious hardships imposed on the waste-producing agencies, waste-form criteria must exclude explosive materials, pyrophoric materials, hazardous materials, and free liquids. However, small quantities of pyrophoric radionuclide metals included with other waste forms may be accepted if they can be handled within the operational guidelines of the WIPP reference repository. Hazardous materials will also be allowed on a non-routine basis if special precautions are taken and advance notice is given. The amount of gas-generating waste in a single storage room is to be limited; a proposed total allowed per room is 10% by weight. Dry powders, ashes, and similar materials will not be accepted for disposal at the repository unless they are immobilized in a binder like glass, concrete, or ceramic. If a particular waste form cannot be immobilized, it may be accepted if it has been doubly contained. Sludges must also be immobilized and must have no free liquid.

One acceptance criterion for CH TRU waste remains unsettled: the permissible amount of combustible material in the waste. A fire-test program, now in progress, will determine whether engineered fire-safety measures are in themselves sufficient to control the fire hazard or whether it will also be necessary to limit the combustible content of the waste. Presently, combustible materials will be accepted for disposal if they are packaged in a disposable steel container or overpack. Any combustible container must be overpacked with a disposal steel container.

Separate criteria are proposed for the design and construction of waste containers. Waste containers must be constructed according to Type A packaging requirements (Section 6.2.1). Their design life is to be at least 10 years in order that containers may be retrieved intact.

Many aspects of package design are also considered in the waste-acceptance criteria. Size, weight, handling accessories, and radiological considerations are detailed in Table 5-1. Most importantly, the surface-dose rate of a package containing CH TRU waste cannot be higher than 200 mrem/hr. Large suppliers must also observe another limit: the surface-dose rate of their shipments, averaged over 3 months, must be no higher than 10 mrem/hr.

Table 5-1. Interim Waste-Acceptance Criteria for CH TRU and RH TRU Waste

Criterion	Contact-handled TRU waste	Remotely handled TRU waste
	WASTE FORM	
Combustibility	No limit, must be packaged in steel containers or overpack	No criterion; quantities are insignificant, and processing will probably not be available
Gas generation	Gas-generating materials in any single storage room may not exceed 10% by weight	No criterion for above reasons
Immobilization	Powders, ashes, etc., must be bound in glass, concrete, ceramic, or other approved matrix; double containment allowed for special cases; sludges must contain no free liquid	Same as for CH TRU waste
Explosives	Not allowed	Same as for CH TRU waste
Pyrophorics	Small quantities of radionuclide-metal pyrophorics may be accepted with other waste forms	Same as for CH TRU waste
Hazardous materials	Allowed only with special procedures and precautions	Same as for CH TRU waste
	CONTAINER	
Design life	10 years to allow retrievability	Same as for CH TRU waste
Structure	Type A requirements	Same as for CH TRU waste

Table 5-1. Interim Waste-Acceptance Criteria for CH TRU and RH TRU Waste (continued)

Criterion	Contact-handled TRU waste	Remotely handled TRU waste
	PACKAGE	
Structure	Type A; any damaged container must be overpacked	Same as for CH TRU waste
Handling	Devices to allow handling by means of a forklift	Axial lifting pintle
Weight	Less than 12,000 pounds	Less than 10,000 pounds
Dimensions	Not larger than 8 by 12 by 9 feet	24-inch diameter, 15-foot length
Radiation		
Surface-dose rate	Not exceeding 200 mrem/hr; sources producing more than 5000 ft^3/yr must produce waste with a 3-month average of less than 10 mrem/hr	Less than 100 rem/hr
Surface contamination	49 CFR 173.398	49 CFR 73.398
Criticality	49 CFR 173, Subpart H	30-gallon drum, 100 grams fissile; 55-gallon drum, 200 grams fissile; DOT-7A, 500 grams fissile
Thermal power	Color code if greater than 0.1 W/ft^3	No criterion

Remotely handled TRU waste

A small fraction (about 2% by volume) of the TRU waste generated by the DOE complex exceeds the 200-mrem/hr limit on the surface-dose rate of CH TRU waste. The surface-dose rates of almost all packaged RH TRU waste range from a few hundred millirem per hour up to perhaps 100 rem/hr. This waste will be handled by shielded equipment designed especially for the purpose.

Acceptance criteria being developed for RH TRU waste are not presently as well developed as the criteria for CH TRU waste. As with CH TRU waste, specifications for waste form, container design, and package design are being considered. Presently, the restrictions on the form of RH TRU waste are quite similar to those for CH TRU waste, except that no criteria have been formulated for gas generators and combustibles. Even if all the RH TRU waste were gas-producing or combustible, there would probably not be enough to cause significant problems at the WIPP reference repository.

The criteria for RH TRU-waste containers are generally the same as those for CH TRU waste: containers are designed to Type A specifications and are designed to be retrievable for at least 10 years. The only differences are the dimensional characteristics of the containers themselves. The shipping casks in which the containers will be transported restrict the size of the container, as does the remote-handling equipment being designed for the reference repository.

The package criteria are shown in Table 5-1. The surface-dose rates must be held below 100 rem/hr.

5.1.3 Spent Power-Reactor Fuel Assemblies

The WIPP reference mission includes an intermediate-scale facility (ISF) for the demonstration, in salt, of the disposal of spent power-reactor fuel. Tentative plans are to store 10-year-old (i.e., 10 years since discharge from the reactor) spent-fuel assemblies from a pressurized-water reactor. Plans for the demonstration are discussed in Section 8.10.

No preliminary acceptance criteria for spent fuel have been developed by the WACSC. It can be anticipated, however, that the criteria for acceptance at the WIPP reference repository will specify canister integrity and lifetime, thermal power, surface-contamination limits, and the configuration of fittings for handling.

5.1.4 Experimental Waste Packages

An isolated area of the reference repository will be dedicated to experiments intended to define the long-term behavior of various waste forms in a bedded-salt storage environment (Section 8.9). Most of the experiments will involve waste that produces high levels of heat and radiation; much of the waste will undoubtedly be prepared especially for the experiments. Spent-fuel

canisters and assemblies will be placed in direct contact with the salt. In the interest of accelerating the experimental results, some of the waste forms will be deliberately degraded before emplacement in the salt. All the wastes used in these experiments will eventually be recovered and removed.

Experimental waste packages will be tailored to individual experiments. Waste form, thermal-power density, and container material and configuration will be closely controlled as an important facet of the quality-assurance program necessary to validate the test results. Acceptance criteria for experimental waste packages, therefore, will be concerned only with safety in handling and will be limited to such characteristics as the design of handling hardware, outer-container integrity, surface-dose rate, and surface contamination.

5.2 ACCEPTANCE CRITERIA ASSUMED FOR ANALYSES REPORTED IN THIS DOCUMENT

As discussed above, the acceptance criteria for TRU waste are still being developed by the Waste Acceptance Criteria Steering Committee. For this reason, two different versions of potential waste-acceptance criteria are used in this document. As explained below, these two versions are used in ways that yield maximum environmental-impact predictions; the waste-acceptance criteria finally selected will produce smaller impacts than the impacts calculated from these assumed criteria.

The following assumed criteria are used in predicting the environmental impacts of shipping TRU waste and handling it at the reference repository:

- No explosive materials
- No pyrophoric materials
- No pressurized gases
- No free liquids
- Combustibles allowed (25% assumed)
- 10% in powder form

These assumptions produce the maximum environmental impacts in transportation and accidents (fires and container failures followed by releases). There would be no releases due to container failure if no portion of the wastes were in powder form; releases due to fire would be minimized if the containers did not contain combustible materials. These assumed criteria, allowing combustibles and 10% of the waste in powder form, are therefore conservative.

In predicting the environmental impacts of preparing the TRU waste at the Idaho National Engineering Laboratory (INEL) for shipment to the repository, the same acceptance criteria were used with two exceptions: only 10% combustibles and no material in powder form were allowed. The waste at the INEL would have to be processed in order to meet these two criteria. Only slagging pyrolysis produces waste meeting these criteria without a separate immobilization step and without sorting and/or shredding of waste. These criteria produce the maximum environmental impacts in preparing waste for shipment; the impacts associated with the construction and operation of a slagging-pyrolysis facility are greatest when the processing meets these restrictive criteria.

The use of the two different sets of waste-acceptance criteria is clearly conservative. One "worst case" set is used in analyzing the impacts of shipping the TRU waste to the repository and handling it at the repository. Another "worst case" set is used in analyzing the impacts of preparing the waste for shipment. Any set finally selected will have a smaller overall impact as long as it is within these bounds.

The WACSC has agreed on the dividing line between what will be considered contact-handled and remotely handled waste. The external surface-radiation level of contact-handled waste containers cannot exceed 10 mrem/hr as a quarterly average for all containers or 200 mrem/hr on any single container. These are limits on the waste as shielded by the packaging, not on the waste inside the package. The 10-mrem/hr average limit will protect the repository work staff by keeping their radiation exposures within the occupational exposure limits specified in 10 CFR 20; the choice of this figure has no environmental consequence. The 200-mrem/hr container limit is taken from the limit specified by the U.S. Department of Transportation in 49 CFR 173. Packages with surface-dose rates above 200 mrem/hr will be handled remotely; the upper limit for remotely handled TRU waste will be 100 rem/hr.

5.3 PROCESSING OF TRANSURANIC WASTE

The interim waste-acceptance criteria described in Section 5.1 and listed in Table 5-1 do not require the CH TRU waste to be free of combustible or gas-producing material. As long as the waste is in a steel overpack, there is no limit to the quantity of combustibles, and as long as the allowed percentage of gas-producing material in individual repository storage rooms is not exceeded, there is no limit to the quantity in a particular container. However, the limitation on combustible and gas-producing material is still a subject of much discussion. Should future experimental evidence establish the need for limiting the quantity of these waste forms, it will be necessary to process the CH TRU waste such as that found at the INEL.

5.3.1 Evaluation of Processing Alternatives

Incineration is considered the only feasible processing alternative for reducing the content of combustible and gas-producing materials. In anticipation that it will be necessary to process TRU waste before shipment from the INEL, numerous analyses have been conducted at the INEL to evaluate the merits of various incineration systems. The analyses assumed that no combustible or gas-producing material would be allowed in the processed waste. In addition, they assumed that the product had to be immobile because interim waste-acceptance criteria require an immobile waste. The analyses examined, in addition to incineration, combinations of pretreatment processes, incineration, and residue-immobilization processes.

The first analysis (FMC, 1977) evaluated nine radioactive-waste incineration processes (acid digestion, agitated hearth, controlled air, cyclone drum, fluidized bed, molten salt, pyrolysis/controlled air, rotary kiln, and slagging) and eight commercial/municipal incineration processes (controlled air, fluidized bed, molten salt, moving grate, multiple hearth, pyrolysis/

controlled air, rotary kiln, and slagging pyrolysis). These processes are briefly described in Appendix F. Because many of the investigated incineration processes produced residues that were not immobile, it was necessary to consider immobilization for treating the residues. The 11 immobilization processes (bitumen, cement, ceramic, clay fixation, glass solution, glass encapsulation, metal matrix, pelletization, plastic materials, salt cake, and slagging) that were considered are briefly described in Appendix F.

The most desirable waste-treatment process for the buried INEL waste was found to be slagging pyrolysis (EG&C, 1977), which requires a minimum of waste preparation before incineration and no further immobilization after incineration. The output of this process is a basaltlike glass slag that is inert, has no combustible or gas-forming material, exhibits a low leach rate, and can be cast into any shape or size. Although this study was conducted for buried waste, its findings are equally applicable to the processing of stored waste.

To insure objectivity, a multicompany task force was established to conduct an independent analysis of various waste-processing concepts for both stored and buried TRU waste at the INEL. The task force consisted of representatives from four DOE contractors and one private firm (Cox et al., 1978).

Of 10 process systems evaluated, three were judged superior: (1) a system using two slagging-pyrolysis incinerators in parallel, each with a capacity of 70,000 kilograms per day; (2) a system having a single slagging-pyrolysis incinerator with a capacity of 200,000 kilograms per day; and (3) a system consisting of an indirectly fired rotary kiln.

The other studies (EG&G, 1977; Kaiser Engineers, 1977) comparing incineration systems came to similar conclusions: slagging pyrolysis is the superior process and holds the highest promise for producing noncombustible, immobile waste products that are free of gas-producing material.

The analyses of slagging pyrolysis have been based almost solely on the characteristics of the defense TRU waste at the INEL. The results are believed to be applicable to waste from other sources. Should it become necessary to reduce the quantities of gas-producing and combustible materials in waste sent to the repository, it is believed that slagging pyrolysis can be readily adapted for processing defense TRU waste at other locations. Furthermore, slagging pyrolysis may well be the best process for treating commercially generated TRU waste.

5.3.2 Slagging-Pyrolysis Incineration

Slagging pyrolysis is a relatively new form of municipal-waste incineration; its original objective was to generate gas that could be used as fuel for industrial or municipal operations. In this process waste material is loaded into a vertical shaft chamber. As the material descends, it passes through a drying zone, a pyrolysis zone, an oxidation zone, and, finally, a slagging zone in the bottom of the chamber. The hot gases driven off at each zone rise and form the fuel for the upper zones. Volatiles collected in the pyrolysis zone may be used as a fuel in a steam boiler or oxidized in an afterburner coupled to heat exchangers. The output of this process is a basaltlike

glassy slag that entraps the ash along with metals and noncombustibles in the waste material. The slag may be cast into any desired shape.

The superiority of the slagging-pyrolysis incinerator comes from its ability to accept a waste feed with only a minimum of sorting and sizing and to produce a residue that, when cast and cooled, does not need further processing. The residue is in a form that is reduced in volume, safer for storage, and safer for handling and transport.

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6 Transportation of Waste to the WIPP Reference Repository

This chapter reviews and evaluates the main features of the system used to transport radioactive waste to the WIPP reference repository: the regulations governing such transport and the organizations involved with them, the packages and packaging systems used for the waste, the routes over which the waste is likely to travel and the range of routing controls that can be exercised, the volume of transported waste and the number of shipments, and the environmental effects of such waste transport under both normal and accident conditions and as a result of intentional destructive acts.

6.1 ORGANIZATIONS

Shipments of radioactive materials are closely regulated for safety. The U.S. Department of Transportation (DOT) has primary responsibility for the regulations that cover the safety of interstate and foreign radioactive-material transport by all means except postal shipments, which are regulated by the U.S. Postal Service. The U.S. Department of Energy (DOE) and the U.S. Nuclear Regulatory Commission (NRC) assist and advise the DOT in the establishment of national safety standards and in the review and evaluation of packaging designs. Intrastate shipments are regulated by the NRC or by state agencies. Several states, including New Mexico and Texas, have entered into formal agreements with the NRC that transfer regulating authority to the states.

6.2 REGULATIONS

All waste packages transported to the WIPP reference repository will comply with DOT regulations, which are designed to insure the safety of the general public from the consequences of transporting radioactive material. The specific regulations are found in the Code of Federal Regulations (CFR) under the following headings:

10 CFR 71	Packaging of Radioactive Materials for Transport and Transportation of Radioactive Material Under Certain Conditions
49 CFR 107	Rule-making Procedures of the Materials Transportation Bureau
49 CFR 171	General Information, Regulations and Definitions
49 CFR 172	Hazardous Materials Table and Hazardous Materials Communications Regulations
49 CFR 173	Shippers--General Requirements for Shipments and Packagings
49 CFR 174	Carriage by Rail
49 CFR 175	Carriage by Aircraft

49 CFR 176	Carriage by Vessel
49 CFR 177	Carriage by Public Highway
49 CFR 178	Shipping Container Specifications
49 CFR 179	Specifications for Tank Cars

These regulations insure safety through standards for packaging and proper handling of radioactive materials. They do not specify routing for the shipment of radioactive material or requirements for vehicle safety. Routing and vehicle safety are governed by other Federal regulations, which are not specific to radioactive materials but cover hazardous materials in general.

The terms "packaging" and "package" are used throughout this section. Packaging is defined as the shipping container; package is defined as the container and its radioactive contents.

6.2.1 Packaging

The primary means for insuring safety during transport of radioactive material is proper packaging. Consequently, the majority of the radioactive-material-transport regulations concern packaging standards.

Three aspects of packaging are considered by the regulations:

1. Containment of the radioactive material, with allowance for heat dissipation if required.

2. Shielding from the radiation emitted by the material.

3. Prevention of nuclear criticality in fissile materials.

Regulations to insure adequate containment

Each radionuclide is classified in one of seven transport groups (revisions pending to 49 CFR 172 may replace transport groups), according to its potential hazard and toxicity. The more hazardous transport groups have lower limits on quantity; that is, for the same type of packaging, less activity of a more hazardous radionuclide is allowed per package. For example, since plutonium-239 is in Transport Group I (the most hazardous group) and strontium-90 is in Group II, less plutonium-239 is allowed per package than strontium-90. In addition, within a transport group, there are different "size" packages. The term "size" in this context refers to the activity of a radionuclide allowed in a package. Of importance to this document are, in order of increasing size, "Type A," "Type B," and "Large Quantity." A Type B package contains more radionuclide activity than does a Type A package.

Any packaging, including Type A, used to contain radioactive material must meet the requirements of 49 CFR 173.393 to prevent dispersal of the radioactive contents and to shield personnel from the contents during normal transport. These packagings must pass tests that simulate the extreme conditions of normal transport. These tests are outlined in 49 CFR 173.398(b) and in 10

CFR 71, Appendix A. Typical Type A packagings are wooden boxes and metal drums.

Quantities of radioactive material exceeding Type A packaging limits can be transported only in Type B packagings, which are strongly accident-resistant containers of various shapes and sizes. Any Type B packaging design must be certified by the NRC or the DOE. The DOE may certify the design of packages such as those designed by a DOE contractor for use by the DOE. The standards for packaging design are found in 10 CFR 71, Subpart C. In addition to meeting the standards for Type A packagings, a Type B package must "survive" certain severe accident-test conditions that demonstrate resistance to high-speed impact, puncture, fire, and submersion (10 CFR 71, Appendix B). In order to be judged as surviving, the Type B packaging must not release any of its radioactive contents except for limited releases of contaminated coolant or gases; it must not allow radiation levels to exceed 1 rem/hr at 3 feet from the package (10 CFR 71.36). Type B packagings that are used for shipments in the Large-Quantity category are subject to additional requirements pertaining primarily to decay-heat dissipation.

Surface contamination on packages, which might be transferable or even dispersible, is limited to levels specified in 49 CFR 173.397, a section that also describes the method for assessing the amount of surface contamination.

Regulations to control radiation exposure

The radiation emitted by the radioactive contents of a package is not completely absorbed by the packaging, but the radiation that is allowed to escape the packaging is regulated to minimize exposure of the public. Packages that will be handled only by the shipper and receiver (shipped in exclusive-use or sole-use vehicles) may not exceed the following dose-rate limits:

1. 1000 millirem per hour at 3 feet from the external surface of the package (closed transport vehicle only).

2. 200 millirem per hour at any point on the external surface of the car or vehicle (closed transport vehicle only).

3. 10 millirem per hour at any point 6 feet from the vertical planes projected by the outer lateral surfaces of the car or vehicle; or if the load is transported in an open transport vehicle, at any point 6 feet from the vertical planes projected from the outer edges of the vehicle.

4. 2 millirem per hour in any normally occupied position in the car or vehicle, except that this provision does not apply to private motor carriers.

Regulations to prevent nuclear criticality

The criticality standards for fissile-material packages are found in 10 CFR 71.33. A package used to ship fissile material must be so designed that it is subcritical if water leaks into the package and/or if any liquid contents leak out. The number of such packages that may be transported

together is also limited. Some quantities and forms of fissile materials cannot be made critical under credible conditions; they are exempted from special fissile-material requirements.

6.2.2 Handling

During handling, the carrier of radioactive materials must perform special actions in addition to those required for other hazardous materials, but since the safety of radioactive-material transport is primarily governed by packaging design regulations, the special actions are mainly limited to administrative actions such as documenting, certifying, and placarding. However, one important action is to insure that radiation levels are not exceeded in any shipment. A special Transport Index (dose rate in millirem per hour at 3 feet from the accessible exterior surface of the package) was developed to aid the carrier in maintaining radiation levels within allowable limits.

6.2.3 Routing

The Federal regulations governing the routing of radioactive-material shipments are limited; the only regulation is that truck carriers with hazardous shipments are to avoid traveling through or near heavily populated areas, crowds, tunnels, narrow streets, and alleys. No similar restrictions apply to rail carriers, however. Federal standards do not rely on restriction of routes to insure the safety of radioactive-material shipments during transit.

Since carriers must be in compliance with the laws, ordinances, and regulations of the local jurisdictions in which they operate, they must observe state and municipal restrictions. Hazardous materials, including radioactive materials, are subject to limited special-routing requirements imposed by a variety of authorities. Authorities in charge of municipalities, turnpikes, tunnels, and bridges place restrictions on hazardous-material shipments. Some cities have restricted all hazardous-material shipments inside their limits.

6.2.4 Vehicle Safety

No additional or special vehicle regulations are imposed on the carrier of radioactive materials beyond those required for a hazardous-material carrier. Vehicle safety is insured by other Federal regulations, which are not specific to vehicles carrying radioactive material. For example, truck safety is governed by the Bureau of Motor Carrier Safety, which imposes vehicle-safety standards on all truck carriers (49 CFR 325, 386-398). Along with other functions, the Bureau conducts unannounced roadside inspections of vehicles and drivers. During an inspection, the condition and loading of the vehicle and the driver's documentation are checked. These checks are performed on all truck carriers, however, not just those carrying radioactive material.

6.3 PACKAGES AND PACKAGING SYSTEMS

Proper packaging design is the foundation of radioactive-material-shipment safety. All wastes transported to the WIPP reference repository will be shipped in packagings that comply with the applicable regulations detailed in Section 6.2. To insure that packagings are safe and meet Federal regulations, the DOE will test and analyze packagings to be used for the repository. Work is under way for developing and testing these packagings. Most development and testing will be performed by a model-and-analysis approach that uses computer-modeling techniques to reduce the required number of full-scale experiments. Several full-scale tests of spent-fuel shipping containers have already been performed, primarily to confirm analytical models used in the design and evaluation of packagings. Once models have been thoroughly confirmed and validated, they will be used extensively, eliminating much of the need for expensive full-scale testing. A formal Safety Analysis Report for Packaging is prepared for each packaging system--a report describing the system and the analyses and tests performed to verify its acceptability. In addition, a quality-assurance program to be carried out during construction and actual use of the packagings will require their frequent inspection.

6.3.1 Contact-Handled (CH) TRU Waste

The predominant waste form to be transported to the repository is CH TRU waste. This waste, characterized by low radiation levels, can be handled and transported without radiation shielding. Because the radioactivity contained in the CH TRU waste packages will exceed the Type A quantity limits, this waste will be shipped in Type B packages.

Contact-handled TRU waste is currently shipped from Rocky Flats to the Idaho National Engineering Laboratory (INEL) in ATMX-600 series railcars under the provisions of DOT Exemption 5948, which allows the shipment of CH TRU waste in ATMX railcars as long as it is packaged in Type A polyethylene-lined drums or plywood boxes coated with fiberglass-reinforced polyester. In addition, drums are prepackaged in steel cargo containers (8 by 8 by 20 feet) that provide an effective third barrier for containment. The ATMX packaging system is considered by the DOT to be equivalent to a Type B packaging. Because no single containment barrier in the system can satisfy the containment-vessel criteria, the NRC and DOE cannot approve the system as a Type B packaging according to the narrow definition in 10 CFR 71 and 49 CFR 173.389(k). Nevertheless, the ATMX cars and inner drums and boxes form a containment system of multiple barriers that, as a single unit, is expected to be at least as strong as a Type B packaging.

Since the ATMX packaging system is presently used for shipping CH TRU waste, it will be described in detail. The DOE-owned ATMX railcar is massive; it incorporates many safety devices, including roller bearings, shock-absorbing draft gear, interlocking couplers to prevent uncoupling in a derailment, and locking-type center pins to prevent the loss of the trucks (swiveling carriages at each end of the railcar) under most circumstances. The underframe is a heavy one-piece steel casting reinforced by welded steel plates to pro-

duce a continuous floor. The superstructure is also very strong because of its massive cross-braced sides. The sides, constructed from steel armor that is nearly 0.5 inch thick, are designed not to buckle during a rollover. The ends of the car are heavily reinforced and designed with a slope that will deflect following or preceding cars over the roof of the car should an accident occur. This extremely strong railcar is appropriately described as able to withstand major catastrophes (Adcock and McCarthy, 1974).

Additional protection for CH TRU waste shipped in the ATMX railcar is afforded by the Type A packagings placed inside. These Type A packagings can be either drums or boxes. Typically, the Rocky Flats drum is a DOT-17C 55-gallon steel drum with a 2.3-millimeter-thick molded polyethylene liner. The Rocky Flats box is a DOT-7A plywood box (4 by 4 by 7 feet) overcoated with a 3-millimeter laminate of fiberglass-reinforced polyester and lined with polyvinyl chloride and fiberboard (Wickland, 1976).

Another packaging, called a Super Tiger, is certified for both truck and rail Type B shipments. An alternative packaging for CH TRU waste, it presently is the only such packaging used for truck shipment. The Super Tiger was designed as a general-use packaging for the shipment of Type B materials; it is frequently used to hold Type A drums or boxes. It has the dimensions of a standard cargo container (8 by 8 by 20 feet), and it can be handled, stored, and shipped in the same manner as any standardized shipping container. The packaging is constructed from two rectangular steel shells separated with rigid fire-retardant polyurethane foam (Hansen, 1970).

The entire outer-steel shell is fabricated from ductile low-carbon-steel plate 3/16 inch thick. This material can elongate by nearly 40%, thus allowing the shell to deform severely without cracking. All corners are lap doubled, continuously seam welded along the overlapping edge, and reinforced with a layer of 3/16-inch plate. In addition, all external edges are protected with a diagonal gusset plate of 12-gage steel. One end of the shell is removable. Ten high-strength 1-inch-diameter bolts secure the container end to the body, and additional joint integrity is provided by four 1-inch-diameter steel dowel pins.

A special formulation of fire-retardant rigid-polyurethane foam was developed for the Super Tiger. This foam, poured in place and allowed to expand between the two steel shells, provides excellent thermal protection and, because of its high energy-absorbing capability, an ideal shock-isolation medium as well.

The steel inner shell, approximately 6 by 6 by 14 feet, has a removable end cap. All edges or joints in the shell are overlapped and double-seam welded in a manner similar to that used for the outer shell. The inner end cover is attached by means of bolts and sealed with soft silicone rubber.

The Super Tiger is an extremely rugged packaging and has been certified to the tests specified in 10 CFR 71, Appendix B. Nevertheless, the Super Tiger and ATMX car may be replaced with new containers currently being developed for greater efficiency in handling the volumes expected at the repository.

6.3.2 Remotely Handled TRU Waste

Remotely handled TRU waste is commonly generated during the decontamination or decommissioning of waste facilities that have handled radioactive materials. Generally composed of piping, valves, machine tools, concrete rubble, etc., it must be shipped in shielded containers. Although several packagings are under consideration for shipments to the repository, two likely configurations are (a) disposable shielded packagings (e.g., concrete-shielded drums used by the Federal Republic of Germany at the Asse repository) transported as CH waste and (b) canisters placed in reusable shielded packagings similar to those used for high-level waste. In either configuration, the waste shipments must be made in packagings that meet Type B specifications.

6.3.3 Commercial-Reactor Spent Fuel

Spent-fuel assemblies from commercial pressurized-water reactors may be emplaced in the WIPP reference repository. Each assembly will have cooled a minimum of 10 years after removal from a reactor, and each will be contained in a canister.

Canister designs under development are approximately 15 feet long and 9 to 15 inches wide. Both cylindrical and rectangular canisters are being considered. The assemblies may be placed into canisters either at the storage site from which they are obtained (assuming canning facilities are available there) or at some other, as yet unspecified, facility. Both legal-weight truck (LWT) and rail spent-fuel shipping casks may be used for transporting the spent-fuel canisters to the repository.

A number of casks of both types are currently available, but some of the current designs would have to be modified to transport canistered spent fuel. The existing casks are about 17 feet long and range from approximately 40 inches in outside diameter for the truck casks to 96 inches in outside diameter for the rail casks. Each LWT cask can hold one spent-fuel canister from a pressurized-water reactor, while some rail casks can transport 10 such canisters.

Most casks use stainless-steel linings for the cask cavity. Thick layers of lead and/or depleted uranium are used to provide gamma shielding in most cask designs. One design, however, uses a foot of stainless-steel-clad carbon steel for this purpose. Casks also employ water, borated water, or hydrogenous resin as neutron shields. The outer steel surface of the cask, either circular or polygonal in cross section, may be smooth, corrugated, or finned to aid in heat conduction. The cask ends are massive steel forgings containing both gamma and neutron shield zones. Impact limiters are generally affixed to each end of the cask to provide an energy-dissipation mechanism in the event of an accident.

6.3.4 Experimental High-Level Waste (HLW)

High-level waste to be used in the experimental program will be placed in canisters before being transported to the repository. Canister designs under consideration range from 1 to 2 feet in diameter and 10 to 15 feet in length. The longer canisters could be effectively transported in casks used for moving spent fuel; the shorter canisters would be transportable in shorter, lighter shipping casks, if they become available.

There are no shipping casks in existence designed specifically for transporting HLW canisters. There are, however, two conceptual HLW cask designs, each of which, if fabricated, would weigh about 100 tons. One design (Peterson and Rhoads, 1978) uses a stainless-steel cavity lining surrounded by a lead gamma-radiation shield. The lead, in turn, is enclosed by a thick stainless-steel structural wall surrounded by a borated-water neutron shield. The cask body is completed by a thick stainless-steel outer wall equipped with cooling fins. The cask lid is made from depleted uranium and a solid hydrogenous material to shield the gamma and neutron radiation, respectively. This cask, 14.5 feet long and 8.2 feet in diameter, would have a capacity of nine 1-foot-diameter, 10-foot-long canisters. Another design (Sutherland, 1978) uses a stainless-steel cavity lining surrounded by a layer of depleted uranium or lead as gamma shielding encased by a stainless-steel structural wall. Water or solid hydrogenous material provides neutron shielding. Copper fins for heat conduction extend from the outer structural wall through the neutron shield zone. A layer of depleted uranium, incorporated in the cask end forgings, and a thick layer of hydrogenous material provide radiation shielding at the cask ends. This cask, 13.5 feet long and 5.5 feet in diameter, would have a capacity of seven 1-foot-diameter, 10-foot-long canisters.

6.4 ROUTES

Although the contact-handled TRU waste to be emplaced in the reference repository is currently intended to come only from INEL, the repository will be designed with the capability to dispose of TRU waste from all other sites in the United States. These sites are the Hanford complex in southeastern Washington, the Los Alamos Scientific Laboratory in north-central New Mexico, the Savannah River Plant in South Carolina on the Georgia border, and Rocky Flats in central Colorado. Rocky Flats ships its waste to INEL; the large inventory at INEL has come mostly from Rocky Flats. By the time the WIPP reference repository is in operation, Rocky Flats is expected to process its waste and may ship it directly to the repository instead of to INEL.

The sources of remotely handled TRU waste are the Oak Ridge National Laboratory (ORNL), INEL, Hanford, and Los Alamos. Even though the RH TRU waste at ORNL is not readily retrievable, the number of RH TRU waste shipments to the repository has been determined from the volumes of waste given by Dieckhoner (Appendix E), which include the volumes at ORNL.

Sources of the commercial high-level waste (HLW) to be used in the experimental program cannot be determined at this time. It is expected, however, that it will come from Battelle Pacific Northwest Laboratories in southeastern Washington; where the high-level waste for experiments comes from is not important to this analysis because the quantities to be shipped are small.

While the specific sources of spent fuel have not been identified either, the General Electric storage facility at Morris, Illinois, is a possible source. Another possibility may be to obtain spent fuel directly from commercial reactors.

In arranging for waste transportation, the DOE will select the mode of transport (rail or truck) and the carrier; it may also select major junction and interchange points along the routes. The carriers will make whatever routing arrangements are necessary and appropriate within the operating authority granted them by the Interstate Commerce Commission. They will probably select routes on the basis of safety, economy, and operating convenience. A number of routes could be selected by the railroads; the number is limited only by existing track. The number of routes for truck carriers is even more varied; this analysis of transportation assumes that truck shipments will follow approximately the same routes as rail shipments. A selection of typical rail transportation routes to the WIPP reference repository from each CH TRU waste source is shown in Figure 6-1. The shipment mileages used in the transportation-impact analyses are shown in Table 6-1.

In principle, routes to the repository could be controlled by the DOE. Specifying routes through areas of low population density could indeed decrease exposure to the general public during normal transport and lessen the

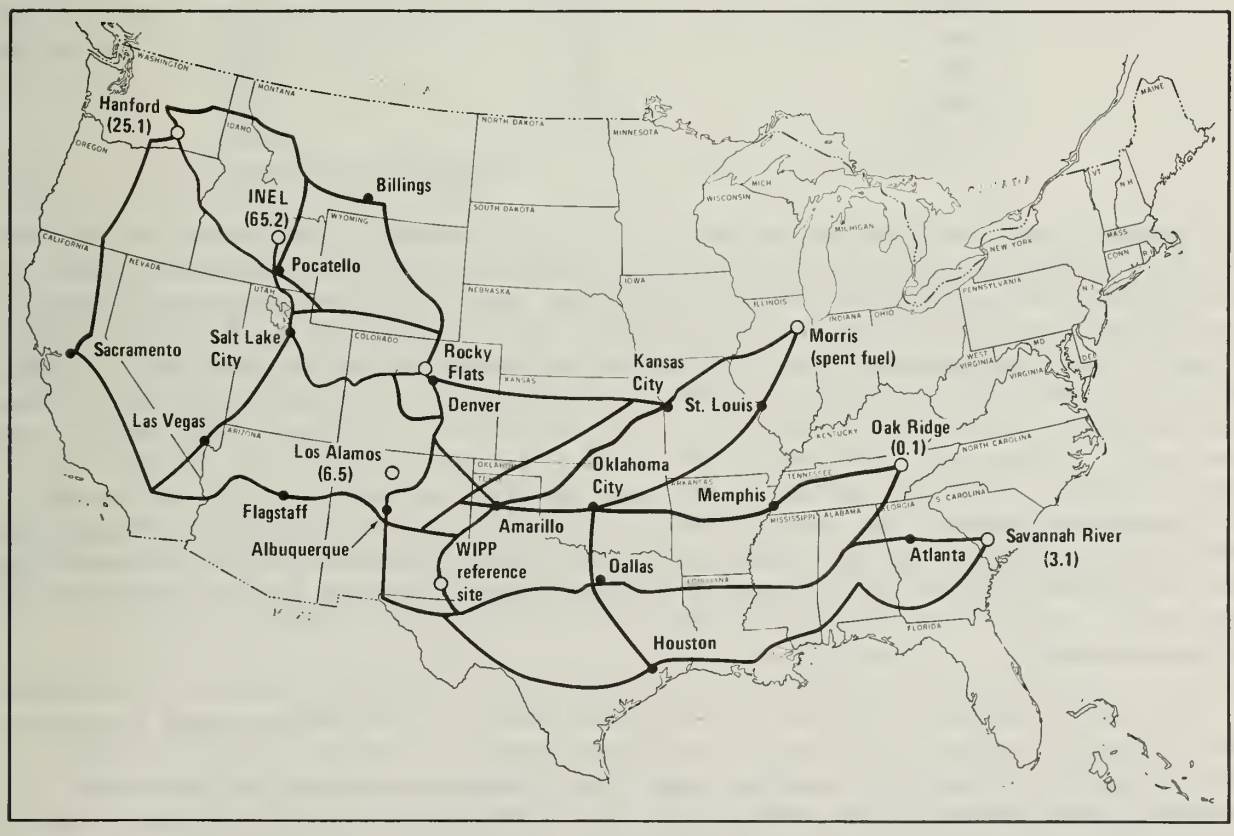

Figure 6-1. Typical rail transportation routes from principal sources. Numbers in parentheses denote the percentage of the total retrievably stored CH TRU waste that is held at each site.

consequences of an accident of given severity. However, careful attention should be given to special routing plans. Many factors must be considered if special routing of shipments is planned, and each specific plan must be reviewed individually because the risk from transportation accidents has two components: probability of occurrence and consequence. By special routing, the consequence component may be reduced. However, if the consequence is reduced by avoiding population centers, the extra mileage traveled may result in an increase in the probability of accident occurrence. The roads avoiding large population centers could be freeways; because of their design, accident rates are reduced, but the allowed high speeds could produce accidents with more-severe consequences. Rails between population centers are often in better condition than lesser-used routes skirting the population centers; since poor roadbed conditions are often the cause of rail accidents, the avoidance of population centers might increase the probability of an accident.

Table 6-1. Shipment Distances

Location	Distance (miles)	
	Truck	Rail
INEL	1200	1750
Hanford	1750	2300
LASL	340	NA
SRP	1500	1500
RFP	700	750
ORNL	1300	1600
Morris	1500	1400

Another level of routing control would be to specify dedicated routes that would be the only routes by which radioactive-material shipments could be made. Two obvious effects would result from having dedicated routes. First, the accident rate would be reduced because the limited number of routes could be more easily maintained than the unlimited number of routes presently available for radioactive material shipment. Second, the population living along the dedicated routes would receive higher radiation doses than they would receive if routes were not dedicated. The population dose, even though possibly reduced, would be concentrated in a smaller segment of the general public, a concentration that would result in higher average individual doses. If dedicated routes are to be adopted, the small gain from decreasing the accident risk must offset the higher individual doses received by the people in the smaller population segment, doses that are received whether or not an accident occurs.

The ultimate level of control--at least for rail shipment--would be to have "special trains" running on dedicated lines. A special train is dedicated to the transport of nuclear waste with no other freight on board and operated under restrictions governing, for example, speed and passing. Completed at the request of the Association of American Railroads and the Interstate Commerce Commission, two studies have examined the change in impact resulting from exclusive use of special trains for shipment of radioactive

materials (Loscutoff, 1977; Smith and Taylor, 1978). These studies, which did not consider dedicated routing coupled with special trains, concluded that special trains would not significantly reduce the radiological risk of radioactive-material transport or increase its overall safety.

It is obvious that implementation of additional routing control must be considered carefully. Presently, the DOE has no plans to limit routes or use special trains for waste shipments to the WIPP reference repository. The WIPP transportation-impact analysis assumes that waste shipments will be placed under no controls in addition to those presently in effect. Implicit in this assumption is that additional or tightened controls would not significantly reduce or increase the overall radiological impact.

6.5 VOLUMES OF WASTE AND NUMBER OF SHIPMENTS

The quantities of waste stored at various storage locations are not precisely known; that is, the estimations of these quantities (Dieckhoner, 1978--see Appendix E in this report) have large uncertainties associated with them. In addition, it has not yet been decided which locations will actually be shipping waste to the WIPP reference repository. This section quantifies the shipment volumes for the various waste types and details how the number of shipments is calculated.

6.5.1 Contact-Handled TRU Waste

The first column of Table 6-2 lists the volumes of CH TRU waste stored at the most important sources. The waste volumes were obtained from Appendix E. It is conservatively assumed that stored waste is shipped from all principal locations but that no buried waste is shipped to the repository from any location. In Figure 6-1, the number in parentheses after the source name is the percentage of the total U.S. retrievably stored CH TRU waste that is stored at that particular source.

Rocky Flats produces much CH TRU waste that has been shipped to INEL in the past; this practice is assumed to continue until the repository becomes operational. By that time, Rocky Flats is expected to be processing all of its new production, which it then may ship to the reference repository.

For CH TRU waste, no volume reduction was assumed because no processing technique has been specified; reduction factors would vary significantly with the technique used.

Table 6-3 presents estimates of the waste volumes that will be contained in the shipments of contact-handled TRU waste. Boxes will be shipped from INEL and Rocky Flats; they were not considered for the other sources since the number of boxes from the other sources is negligible. The volume-per-shipment numbers were generated from the numbers of boxes or drums that could be shipped in a Super Tiger or ATMX railcar.

Table 6-2. Volume of CH TRU Waste Shipped per Year

Location	Volume (ft^3) Backlog waste	Backlog waste transported per year[a]	New waste production per year	Total waste shipped per year
INEL (box)	7.0+5[b]	7.0+4	2.3+4[c]	9.3+4
INEL (drum)	1.3+6	1.3+5	4.5+4	1.8+5
Hanford (drum)	7.7+5	7.7+4	4.2+4	1.2+5
LASL (drum)	2.0+5	2.0+4	2.5+4	4.5+4
SRP (drum)	9.5+4	9.5+3	7.1+3	1.7+4
RFP (box)	None	None	6.7+4	6.7+4
RFP (drum)	None	None	3.3+4	3.3+4
TOTAL	3.1+6	3.1+5	2.4+5	5.5+5[d]

[a]Assumes backlog volume is transported in 10 years.
[b]$7.0+5 = 7.0 \times 10^5$.
[c]From limited sources other than INEL.
[d]This value is a best estimate, but the uncertainties in it may be as high as +200%, -50%.

The volume of waste shipped per year from each location is found in Table 6-2. It is estimated that one-third of all INEL contact-handled TRU waste will be shipped in boxes and two-thirds in drums. New production from Rocky Flats is expected to be two-thirds boxes and one-third drums. The backlog of waste is estimated to be eliminated during a 10-year campaign, although the existing fleet of ATMX cars and Super Tigers is insufficient to work off the backlog in 10 years. New production volumes were taken from Appendix E except for Rocky Flats; estimates of new production at Rocky Flats are based on engineering judgment. The total volume shipped each year is the sum of backlog production and new production. Even by working off the backlog volume in 10 years, the total volume shipped each year will be somewhat less than the maximum throughput of the reference repository as defined in the Conceptual Design Report (Sandia, 1977).

Table 6-3. Volume of CH TRU Waste in a Shipment

Mode	Container	Volume of container (ft^3)	Containers per shipment	Waste volume per shipment (ft^3)
Rail[a]	Box	112	24	2700
Rail	Drum	7.4	120	930
Truck[b]	Box	112	8	900
Truck	Drum	7.4	42	310

[a]ATMX railcar assumed for rail shipment.
[b]Type B container for truck shipment assumed to hold 8 boxes.

Tables 6-2 and 6-3 were used to generate Table 6-4, which presents the number of shipments of CH TRU waste to the WIPP reference site per year. One additional assumption was made to generate the number of shipments: 25% by volume was assumed to be made by truck and 75% by rail in order to be consistent with the WIPP Conceptual Design Report. The only exception is made for the Los Alamos Scientific Laboratory, which is not serviced by a rail spur and will ship only by truck.

Table 6-4. Annual Shipments of CH TRU Waste

Location	Rail		Truck	
	Waste volume (ft^3)	Number of shipments	Waste volume (ft^3)	Number of shipments
INEL (box)	7.0+4[a]	26	2.3+4	26
INEL (drum)	1.4+5	155	5.0+4	161
Hanford (drum)	9.0+4	97	3.0+4	97
LASL (drum)	NA	NA	4.5+4	145
SRP (drum)	1.3+4	14	4.0+3	13
RFP (box)	5.0+4	19	1.7+4	19
RFP (drum)	2.5+4	27	8.0+3	26
TOTAL	3.8+5	338	1.8+5	487

[a] 7.0+4 = 7.0×10^4.

6.5.2 Remotely Handled TRU Waste

The number of shipments of RH TRU waste was determined using methods identical with those used for CH TRU waste. The backlog-waste volumes were obtained from a report by Dieckhoner (Appendix E). As suggested in Section 6.3.2, RH TRU waste could be shipped in at least two configurations. To determine the number of shipments, the RH TRU waste was assumed to be canistered and placed in heavily shielded casks. The volume of RH TRU waste in a shipment is presented in Table 6-5. Five canisters were assumed for each rail shipment and one canister for each truck shipment. Using the volume-shipped-per-year values from Table 6-6 and the volume-per-shipment values from Table 6-5, the annual number of shipments of RH TRU waste was calculated for each source location (see Table 6-7).

Table 6-5 Volume of RH TRU Waste in a Shipment

Mode	Volume of container (ft^3)	Containers per shipment	Waste volume per shipment (ft^3)
Rail	42	5	210
Truck	42	1	42

Table 6-6. Volume of RH TRU Waste Shipped per Year

Location	Volume (ft^3)			
	Backlog waste	Backlog waste transported per year[b]	New waste produced per year	Total waste shipped per year
LASL	8.0+3[a]	8.0+2	7.1+2	1.5+3
ORNL	4.7+4	4.7+3	2.6+3	7.3+3
Hanford	8.0+3	8.0+2	8.0+2	1.6+3
INEL	1.4+4	1.4+3	2.8+3	4.2+3
TOTAL	7.7+4	7.7+3	6.9+3	1.5+4

[a]8.0+3 = 8.0×10^3 = 8000.
[b]Assumes backlog is transported in 10 years.

Table 6-7. Annual Shipments of RH TRU Waste

Location	Rail		Truck	
	Waste volume (ft^3)	Shipments	Waste volume (ft^3)	Shipments
LASL	NA	NA	1.5+3	36
ORNL	5.5+3	26	1.8+3	43
Hanford	1.2+3	6	4.0+2	10
INEL	3.1+3	15	1.1+3	26
TOTAL	9.8+3	47	4.8+3	115

6.5.3 Spent Fuel

On the assumption that the spent-fuel canisters and shipping containers will be those described in Section 6.3.3, the number of canisters of spent fuel per shipment was estimated for both rail and truck. On the basis of known cask capacities, it was assumed that 10 canisters of pressurized-water-reactor (PWR) spent fuel will be shipped per rail shipment and 1 PWR canister per truck shipment. Only PWR spent fuel was considered in the impact evaluation because it is likely that only PWR spent fuel will be deposited in the WIPP. It was assumed that all the spent fuel would be delivered to the repository during a 4-year period. Using the 25:75 volume split for truck and rail shipments, respectively, and a total shipment of 1000 spent-fuel canisters, 19 shipments of spent fuel per year will be made by rail and 63 shipments per year by truck.

Waste generated at the reference repository and the high-level waste to be used in the experimental program were not considered in the impact study because their quantities are so low that their contribution to the impacts of transportation will be small by comparison to that of the TRU waste and the spent fuel.

6.6 IMPACT OF WASTE TRANSPORT DURING NORMAL CONDITIONS

Different forms of radioactive waste will be shipped to the WIPP reference repository from various locations throughout the United States, by various modes of transport, and in various packagings. All shipments will comply with Department of Transportation requirements to guard against unnecessarily exposing the public to radiation. After defining the conditions of normal transport and outlining procedures used in the impact analysis, this section presents the impacts of waste transport during normal conditions.

6.6.1 Conditions of Normal Transport

In normal transport, the package of radioactive material arrives at its destination without releasing its contents. The potential exposure of people to radiation could arise only from the radiation emitted by the radioactive material inside the shipping containers. Radiation shields are incorporated in packaging design to protect the public and associated handlers. As a radioactive shipment passes by, it exposes the nearby population at a very low dose rate; after it has passed, however, no further exposure occurs.

People nearest the transported radioactive materials receive the greatest doses. The population groups exposed to radiation are, in order of decreasing exposure, those who directly handle waste packages; people working in the vicinity of the packages and those accompanying them (train crew or truck drivers); and bystanders, including those living or working along the route, passing motorists, and train passengers. The exposure levels will be consistent with Federal regulations.

In the analysis of waste transport to the reference site, calculations based on these conditions of normal transport evaluated the doses received by handling crews as well as by the general public.

6.6.2 Procedures Used in Analysis

This analysis uses the methods recommended and used by the U.S. Nuclear Regulatory Commission in its environmental statement on the transportation of waste, NUREG-0170 (NRC, 1977). These methods provide quantitative estimates of doses that might be expected by the general public as a result of transporting radioactive material to the repository. The normal transportation dose was evaluated by the RADTRAN computer code (Taylor and Daniel, 1977), a code actually used in preparing NUREG-0170.

The normal transportation dose is evaluated using information contained in three models within RADTRAN (Figure 6-2). The standard shipment model requires user input about the materials shipped, the transport index (dose rate in millirem per hour at 3 feet from the accessible exterior surface of the package), type of shipping container, number of shipments per year, number of miles per shipment, and mode of shipment. The transportation model requires such information as traffic patterns and miscellaneous shipment information. The population-distribution model is used to define population densities along shipping lanes.

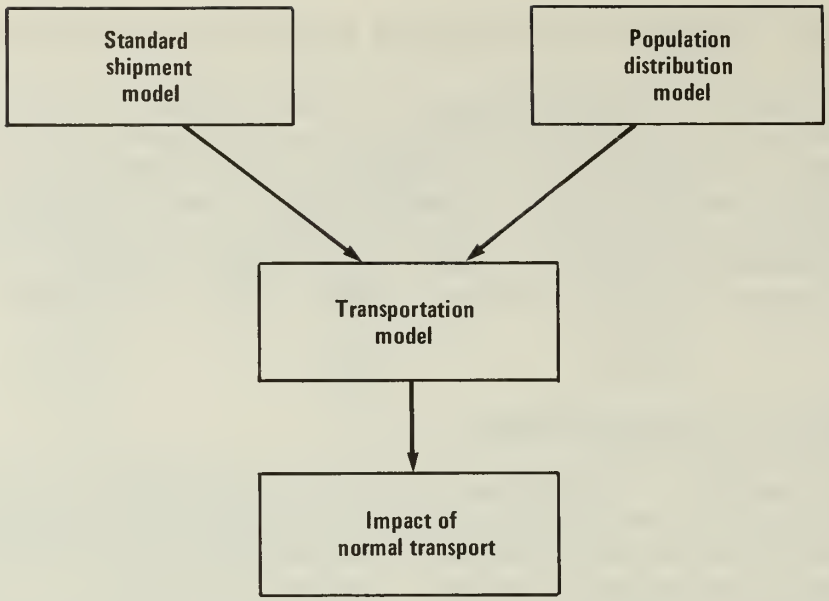

Figure 6-2. RADTRAN models used for normal transport calculations.

The assumed number of shipments of contact-handled TRU waste from the most important sources is given in Section 6.5. It was conservatively assumed that all stored waste at each of the locations would be sent to the reference repository. Buried waste, on the other hand, was not assumed to be sent, even from INEL. The Rocky Flats Plant (RFP) produces much contact-handled TRU waste, but it has been shipped to INEL in the past; such a practice is assumed to continue until the reference repository becomes operational. It is assumed that by then the RFP will process all of its new production and then ship it directly to the repository. The quantities of RH TRU waste at ORNL referred to by Dieckhoner (Appendix E) are, for practical purposes, not retrievable. Nevertheless, ORNL was assumed to be the primary source. The number of shipments of RH TRU waste is also given in Section 6.5. It was assumed that all the spent fuel would be delivered to the repository during a 4-year period. Using the 25:75 volume split for truck and rail shipments, respectively, and a total shipment of 1000 spent-fuel canisters, 19 shipments of spent fuel per year will be made by rail and 63 shipments per year by truck.

Table 6-8 presents selected data used as input to RADTRAN. Much of the information was based on engineering judgment and is consistent with a recent RADTRAN analysis of truck and rail transport (Smith and Taylor, 1978). Much of the information is conservative and will result in dose values greater than expected. The conservatism is necessitated, as in the estimation of the fractions of travel in regions of different population density, by lack of more detailed and better documented information.

6.6.3 Results of the Analysis

The results of the RADTRAN analysis are presented in Tables 6-9, 6-10, and 6-11. The population doses are given in units of man-rem. The results are the total doses received by persons living along each shipment route, motor-

Table 6-8. Miscellaneous Input to the RADTRAN Code

Parameter	Truck	Rail
Number of crewmen	2	5
Mean velocity while crew is aboard	51.5 mph	38 mph
Distance from source to crew	10 ft	500 ft
Stopover in high-population zone	1 hr	0
Stopover in medium-population zone	5 hr	0
Stopover in low-population zone	2 hr	24 hr
Velocity in high-population zone	15 mph	15 mph
Velocity in medium-population zone	25 mph	25 mph
Velocity in low-population zone	55 mph	40 mph
Fraction of travel in high-population zone	0.05	0.05
Fraction of travel in medium-population zone	0.05	0.05
Fraction of travel in low-population zone	0.90	0.90
Traffic count in high-population zone	2800 cars/hr	5 trains/hr
Traffic count in medium-population zone	780 cars/hr	5 trains/hr
Traffic count in low-population zone	470 cars/hr	1 train/hr
People per vehicle	2	5
CH TRU dose rate at surface of Super Tiger or ATMX car	2 mrem/hr	2 mrem/hr
RH TRU dose rate at 6 feet from surface of Super Tiger or ATMX car	10 mrem/hr	10 mrem/hr
Spent-fuel dose rate at 6 feet from cask surface	10 mrem/hr	10 mrem/hr

ists traveling in the same and opposite directions, people around the shipment while it is stopped, and the transportation crew.

The significance of the population doses can be examined by comparing them with the doses received by the same population from natural background radiation. The doses for persons living along each shipment route, for example, can be compared directly to the natural-background doses that would be received by people living within half a mile of the shipping route. At this distance doses from transportation become negligible. To make this as specific as possible, consider the LASL truck route. Approximately 350,000 people live in the 1-mile-wide strip between Los Alamos and the WIPP reference site. This population estimate is high, but it is the same number that was calculated by RADTRAN from the conservative input; the conservatism is a result of averaging population densities for routes from all sources. At an average elevation of 5000 feet, each individual would receive about 0.125 rem per year from natural radioactivity (NCRP, 1975). Therefore, the population dose resulting from natural radioactivity in man-rem is 44,000 for the LASL

Table 6-9. Calculated Radiation Doses from Normal Transportation of CH TRU Waste

Origin and mode	Number of shipments per year	Miles per shipment	Annual dose (man-rem)				
			Population surrounding route while moving	Passing motorists	Population surrounding route while stopped	Crew	Total
INEL (box)							
Truck	26	1200	0.096	0.049	0.16	2.4	2.7
Rail	26	1750	0.34	0.0003	0.007	0.01	0.37
INEL (drum)							
Truck	161	1200	0.59	0.31	0.99	14.9	16.7
Rail	155	1750	2.1	0.002	0.04	0.08	2.2
Hanford							
Truck	97	1750	0.52	0.27	0.60	13.0	14.4
Rail	97	2300	1.6	0.001	0.03	0.06	1.7
LASL							
Truck	145	340	0.15	0.08	0.89	3.8	5.0
SRP							
Truck	13	1500	0.06	0.03	0.08	1.5	1.7
Rail	14	1500	0.16	0.0001	0.004	0.006	0.17
RFP (box)							
Truck	19	700	0.04	0.02	0.12	1.0	1.2
Rail	19	750	0.11	0.0001	0.005	0.004	0.12
RFP (drum)							
Truck	26	700	0.06	0.03	0.16	1.4	1.7
Rail	27	750	0.15	0.0001	0.008	0.006	0.17
TOTAL	825		6.0	0.79	3.1	38.2	48.1

truck route. The 1.0 person-rem dose, given in Table 6-10 for the total normal-transport impact, is only 0.002% of the dose received by the same population from natural sources.

Similar comparisons can be made for the other doses predicted by the RADTRAN analysis. They show that the dose to the general public from transportation of waste to the WIPP is many times smaller than the dose received from natural background.

Table 6-10. Calculated Radiation Doses from Normal Transportation of RH TRU Waste

Origin and Mode	Number of shipments per year	Miles per shipment	Annual dose (man-rem)				
			Population surrounding route while moving	Passing motorists	Population surrounding route while stopped	Crew	Total
INEL							
Truck	26	1200	0.29	0.15	0.49	2.4	3.3
Rail	15	1750	0.26	0.0002	0.005	0.01	0.27
Hanford							
Truck	10	1750	0.16	0.08	0.19	1.3	1.8
Rail	6	2300	0.13	0.0001	0.002	0.005	0.14
LASL							
Truck	36	340	0.12	0.06	0.68	0.95	1.8
ORNL							
Truck	43	1300	0.53	0.27	0.82	4.3	6.0
Rail	26	1600	0.40	0.0004	0.01	0.016	0.42
TOTAL	162		1.9	0.56	2.2	9.0	13.7

Table 6-11. Calculated Radiation Doses from Normal Transportation of Spent Fuel from Morris, Illinois

Origin and Mode	Number of shipments per year	Miles per shipment	Annual dose (man-rem)				
			Population surrounding route while moving	Passing motorists	Population surrounding route while stopped	Crew	Total
Truck	63	1500	0.89	0.46	1.2	7.3	9.8
Rail	19	1400	0.25	0.0002	0.007	0.01	0.27
TOTAL	82		1.1	0.5	1.2	7.3	10.1

[a]For 4 years only.

6.7 IMPACT OF WASTE TRANSPORT DURING ACCIDENT CONDITIONS

This section discusses the potential impacts of transportation accidents on the general public. It addresses the questions: What are the effects of an accident that results in some release of radioactive material? What is the likelihood of these accidents?

This transportation-accident analysis is basically a consequence analysis. Accident scenarios were developed to model low-probability transportation accidents. Emphasis was placed on describing hypothetical accidents that, although unlikely, could occur. After development of the scenarios, the quantities of released radioactive material were estimated. From these release estimates, from an assumed population distribution surrounding the accident location, and from the climatic conditions at the time of the accident, an assessment was made of the effects of the accident on the public. Using the assumed conditions of release, the probability of release was estimated from data available from a report by Dennis (1978) and from NUREG-0170 (NRC, 1977).

6.7.1 Accident Conditions

Most transportation accidents would not be severe enough to release significant amounts of radioactive waste from the packagings that will be used for the WIPP reference repository. In all scenarios, DOT Type B packagings were assumed since the radioactivity content of all expected shipments will exceed Type A packaging limits. Because Type B containers are presently available and are used for routine transport, their characteristics, as described in NUREG-0170, were used in estimating the amount of material released in all the scenarios, including those describing accidents with RH TRU waste and spent fuel.

All Type B packagings are certified to survive sequential exposure to a series of test environments. These test environments damage Type B packagings to levels that would be expected if the packages were actually involved in severe transportation accidents. The complete test sequence incorporates the following series of tests in the order indicated:

a. Drop test--a 30-foot drop onto an unyielding target.
b. Puncture test--a 40-inch drop onto a 6-inch-diameter probe.
c. Thermal test--a 30-minute duration fire at 1475°F.
d. Water immersion test--an 8-hour submersion in water.

Dennis (1978) studied actual rail and truck accidents. Figures 6-3 and 6-4, taken from his report, show the cumulative probability of such accidents as a function of the velocity change of the packaging. These figures can be used to determine what percentage of accidents result in environments at least as severe as the environments produced during testing of Type B packagings.

Figure 6-3 displays the cumulative probability of occurrence of transport accidents versus velocity change during truck or rail accidents. The greater the packaging velocity is at impact, the greater the severity of the impact. Similarly, Figure 6-4 illustrates the cumulative probability of occurrence

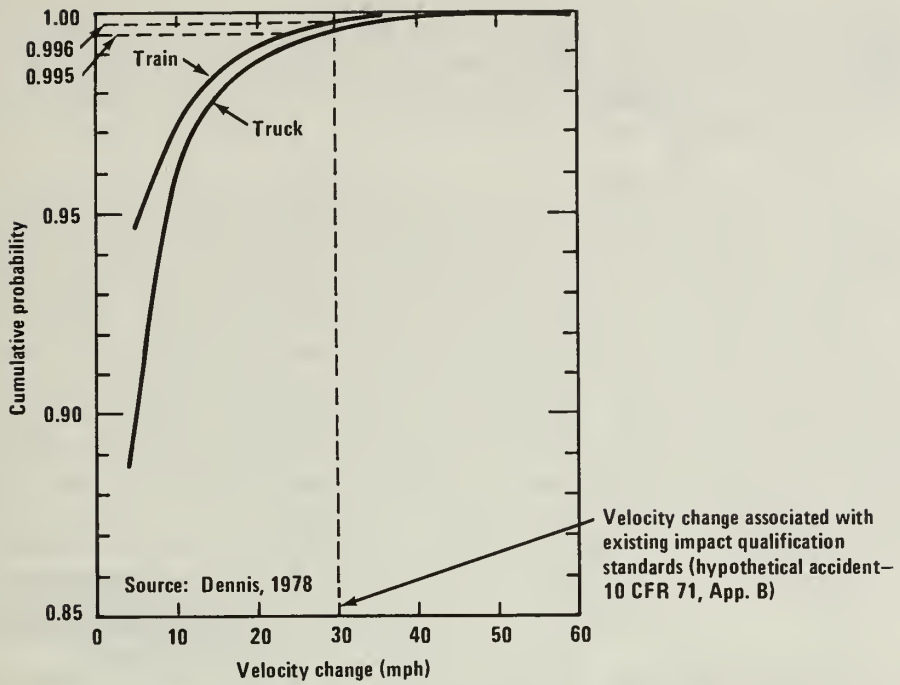

Figure 6-3. Cumulative probability of velocity changes due to impact, given a reportable truck accident or a reportable train accident.

versus the fire duration of a truck or rail accident. The measure of fire severity is the fire duration in minutes. The existing certification test standards of Type B packagings are superimposed on Figures 6-3 and 6-4. The protection levels provided by the qualification test sequence for Type B packagings for the impact and fire environments are given in Table 6-12.

The information in Table 6-12 may be stated in a different manner. The existing drop test results in a 30-mph impact velocity on a rigid surface for the candidate packaging design. The transporting vehicle would have to be traveling at a much greater velocity in order to have its package impact at a velocity equivalent to the 30-mph impact. Thus, 99.5% of all truck accidents and 99.6% of all rail accidents are less severe (less intense) than the regulatory requirements for the impact environment. Similarly, the fire environment of the standards provides protection against fire environments unlikely to be exceeded in 99.9% and 99.8%, respectively, of all truck and rail accidents resulting in fire.

Table 6-12. Percentage of Accidents That Are Less Severe Than Test Conditions in Regulatory Standards

Transport mode	Impact	Fire
Truck	99.5%	99.9%
Rail	99.6%	99.8%

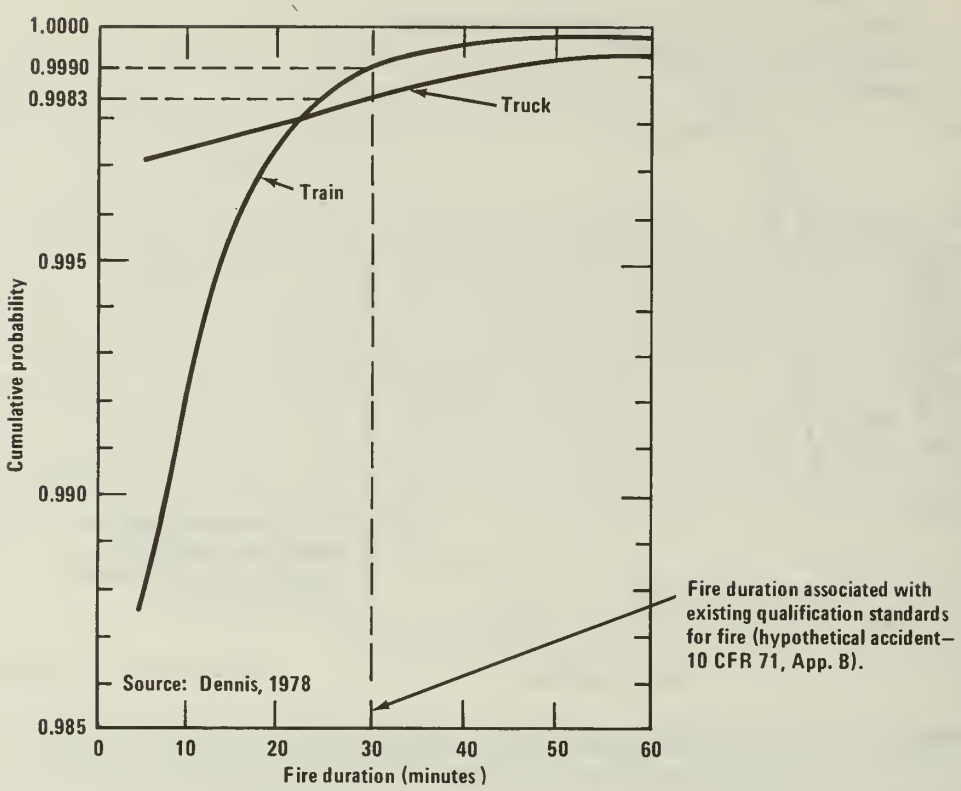

Figure 6-4. Cumulative probability of fire durations, given a reportable truck accident or a reportable train accident.

A broader perspective of the severity of transportation accidents can be obtained by considering personal-injury statistics associated with truck accidents. During 1969-1972, there were 179,070 reportable truck accidents; these resulted in 1007 truck-driver fatalities and 20,766 truck-driver injuries (Dennis, 1977, pp. A-6, A-7). Consequently, there were no injuries in 87.8% and no deaths in 99.4% of all the reported accidents.

The existing licensing requirements for radioactive-material packages provide very high protection levels and the regulatory test environments are much more severe than the vast majority of transportation accidents.

6.7.2 Procedure: Construction of Accident Scenarios

As shown in Table 6-12, the 10 CFR 71 licensing criteria tests provide complete protection for all but a very small fraction of truck and rail accidents involving Type B packages. However, in this section, accidents more severe than those covered by 10 CFR 71 are considered for purposes of analysis.

This analysis is based on four different accident scenarios described below under separate headings. Each of the scenarios was assumed to take place in two locations with different population densities and distributions. As models of typical urban population centers along the routes that will carry

waste to the repository, the study uses detailed population data for a large urban area (Albuquerque, N.M.) and for a small urban area (Carlsbad, N.M.). The use of specific data does not restrict the applicability of the results of the study; these particular urban areas were selected because their population densities are representative of many other cities along potential routes.

The climatic conditions selected are very conservative; the conditions that lead to the greatest population doses have been chosen. Because conditions prevailing at the time of a hypothetical accident are likely to vary widely, there are no typical conditions representative of all the urban areas along the route. Pasquill stability category F, a wind speed of 1 meter per second, and an inversion layer at 1000 meters were used to calculate the dispersion of the radioactive material released. These are typical of night conditions with limited mixing and, therefore, highest concentrations. A release height of 20 meters was judged to be representative of the conditions surrounding the accidents--particularly those involving fire. The released radioactive material was assumed to pass into the most densely populated areas in the modeled regions; in reality, the wind would blow toward the most densely populated areas only a fraction of the time. Population densities out to a 50-mile radius were used in the calculation.

The computer code AIRDOS-II (Moore, 1977), used to compute the dispersal of the radioactive material and to predict its movement through the biosphere to the general public, assumes that the accident locations and surrounding terrain are flat and that the plume of dispersing radioactive material does not interact with buildings or other surface irregularities. In an urban environment with buildings, surface irregularities, and thermal anomalies, a plume will disperse more rapidly than in open country. Consequently, stability category E or F is more appropriate than G (most stable). Diffusion conditions typical of F stability were chosen to obtain a conservative mid-range atmospheric condition. No plume scavenging from rain or snow was assumed.

The quantity of radionuclides released, population densities, and meteorological data were input to AIRDOS-II, which calculates the effects to the general public. The final effects were evaluated in terms of radiation dose for external exposure and radiation-dose commitment for inhaled material. No ingestion of the dispersed material was assumed because health authorities, acting after an accident, would remove contaminated food from distribution. The primary radiation dose results from the continuing exposure to inhaled radioactive material that the body retains.

Hypothetical rail accident involving CH TRU waste

The assumed rail accident involves a flatbed railcar loaded with three Type B packages. Each package contains 42 drums of CH TRU waste. The flatbed car is assumed to derail during a violent train collision near the center of an urban area. It must be emphasized that the possibility of such a violent accident in an urban area is remote because in many urban areas speeds are decreased for other rail traffic and for movement over switches. The crushing forces from the impact cause one-half the drums to release their contents within the packaging. Only one-half release their contents because the drums will provide their own buffer; i.e., the drums away from the impact surface are cushioned by surrounding drums. Approximately 10% of the released material within the packaging might be released as assumed in NUREG-0170 for a

similar accident. Thus, under the assumptions proposed here, the equivalent of approximately 6.4 drums of CH TRU waste might be released. The scenario is quite conservative since the CH TRU waste produced after 1981 is expected to be processed into a solid form. Release of material from a drum containing material produced after 1981 would require severe pulverization.

For the assumed climatic conditions in this scenario, i.e., low wind speeds and generally stable conditions, only the finest powder is likely to be entrained in the air and transported beyond the immediate vicinity of the packaging. Very little of the CH TRU waste shipped to the repository will be fine powder; it is expected that much will be metal scrap, rags, sludge, and sludge-concrete mix. Considering data presented by Shefelbine (1978), the WIPP study assumed that 10% of the CH TRU waste will be in a fine-powder form after the accident. Thus, of the exposed CH TRU waste, only 0.64 drum is assumed to be in a powder form that could become airborne. This assumption is likely to be conservative because a proposed waste-acceptance criterion is to limit the allowed quantity of particles less than 10 microns in diameter to 1% by weight.

Empirical data have been obtained for air entrainment of dry powders deposited on various surfaces (Mishima and Schwendiman, 1970 and 1973b); the entrainment fractions for a dry powder deposited on a roadlike surface were used for this scenario. Mishima and Schwendiman found empirically that 0.14% of a dry powder was entrained after being subjected to a 2.5-mph wind for 6 hours. This value was obtained under carefully controlled conditions in which dry powder was placed gently on the roadlike surface. This percentage is probably not large enough for this scenario, in which some of the powder might be dispersed as it falls to the roadbed. For this reason, 1.4% of the dry powder (a value 10 times the experimental value) is estimated to be entrained in air during the estimated 6-hour cleanup of the accident scene. The experiments also indicated that only 62% of the airborne powder was of respirable size.

In summary for this scenario, the equivalent of 0.64 drum is exposed to the air as a dry powder, 1.4% of the powder is entrained in the air, and 62% of the entrained powder is respirable. Thus, the equivalent of 0.55% of one drum is entrained and respirable. From Appendix E, the radioactivity released and respirable is

Isotope	Release (Ci)
Pu-238	2.2-4
Pu-239	2.6-3
Pu-240	6.4-4
Pu-241	1.6-2
Am-241	4.3-5

Hypothetical truck accident involving CH TRU waste

A truck carrying one Type B package containing 42 drums is assumed to crash near the center of an urban area. A subsequent fire is assumed to engulf the packaging and its contents for half an hour. As in the rail accident, one-half of the drums are crushed from shifting caused by the impact

force. They release their contents within the packaging, and 10% of the loose material within the packaging is assumed to be released. Thus, the equivalent of two drums of uncontained waste may be exposed to the fire. From information in the report by Shefelbine (1978), about 25% of the CH TRU waste is assumed to be combustible in the form of rags and paper. Therefore, it is assumed that about 0.5 drum of CH TRU waste is released and combustible.

Data have been obtained from experiments in which combustible materials contaminated with simulated TRU nuclides have been burned. Mishima and Schwendiman (1970 and 1973a) have measured releases for a variety of waste forms and confinements. From those releases, it is assumed that 1.0% of the TRU waste in the combustible material is airborne and respirable. In addition, there may be additional respirable material from solid noncombustible materials (as discussed for the hypothetical rail accident). These two sources provide the total airborne release, about 0.65% of a drum's contents:

Isotope	Release (Ci)
Pu-238	2.7-4
Pu-239	3.1-3
Pu-240	7.8-4
Pu-241	1.9-2
Am-241	5.1-5

Hypothetical Rail Accident Involving RH TRU Waste

A shipping cask for RH TRU-waste will be heavily shielded and capable of dissipating heat generated by the waste inside. A cask used for rail transport would be larger and heavier than a cask used for truck transport and would carry greater quantities of waste.

The hypothetical RH TRU waste accident involves a rail flatcar loaded with a cask containing five canisters of RH TRU waste. After a violent train wreck in an urban area, the cask becomes enveloped in a fire that lasts about an hour. As a result of impact and fire, volatile fission products contained in the canisters are assumed to be released. Breeching of the cask and heating of the waste to the point of volatilizing the cesium-137 are highly unlikely because the casks are so massive. Making such an unlikely assumption adds even more conservatism to this scenario. It is further assumed that 1% of the cesium-137 is released to the interior of the cask and that 10% of the released cesium-137 escapes from the cask to the environment. Since there are 2.1 curies of cesium-137 in each of the five canisters (as described in Appendix E), the release to the atmosphere during this scenario is

Isotope	Release (Ci)
Cs-137	0.01

Hypothetical rail accident involving spent-fuel shipments

The accident assumed for spent fuel is identical with that assumed for RH TRU waste. Because a rail cask carries more spent fuel than a truck cask, an accident involving a rail cask damaged to the same extent as a truck cask

would be potentially more serious. Thus, this accident presents an upper limit to the consequences of possible accidents with spent fuel.

It is assumed for this scenario that 30% of the krypton-85 and 1% of the cesium-134/cesium-137 are released to the interior of the cask. Then, all of the krypton-85 is assumed to escape to the environment while 10% of the released cesium isotopes escape. Since each spent-fuel canister contains 2600 curies of krypton-85 and 44,000 curies of cesium-134/cesium-137 (as described in Appendix E) and since there are 10 canisters in a cask, the releases to the atmosphere during this scenario are

Isotope	Release (Ci)
Kr-85	7800
Volatile fission products	440

In this calculation cesium-137 was used to represent all the volatile fission products in the radionuclide inventory.

6.7.3 Results of the Analysis

In this accident analysis, inhalation of radionuclides is the primary pathway to man. When radioactive material is inhaled, a fraction of it is retained in the body. Retained material continues to irradiate the body until it can decay or be removed by biological processes. By convention, the dose given off by radioactive material while in the body is integrated over a 50-year period after inhalation. This integrated dose is called the 50-year dose commitment. For materials that decay rapidly or are removed quickly, most of the dose commitment is received during the first year or two. For long-lived materials that remain in the body, the dose is relatively uniform over the entire 50 years. The results of the accident analysis are given in terms of the 50-year dose commitment to the total body, to bone, and to the lungs.

For the assumed meteorological conditions, the individual receiving the maximum dose will be a person remaining one-half mile from the accident during the entire time the cloud of radioactive material is passing; Table 6-13 presents the doses received by this hypothetical person. As the distance increases beyond one-half mile, the doses decrease steadily. Because of the assumed height of the release, the calculated doses also decrease steadily as distance decreases below one-half mile. Conceivably, people at the scene of the accident could receive larger doses than the person standing one-half mile from the wreck. In an emergency radiological situation, however, local government control could keep people from handling the wastes or remaining near the scene of the accident. In addition, an accident of this severity will result in a relatively large exclusion region inside which people will have to contend with wreckage, fire, etc., and where traumatic bodily injury will probably be much more significant than the radiological hazard.

Table 6-13. Dose to an Individual[a]

Scenario	Dose commitment (rem)		
	Bone	Lung	Whole body
CH TRU rail	0.49	0.025	0.012
CH TRU truck	0.59	0.029	0.014
RH TRU	0.00003	0.000007	0.00003
Spent fuel	1.2	0.30	1.1

[a]Maximum dose to an individual one-half mile from the accident.

The calculated doses are very small, particularly if the numbers in the tables are compared to a 50-year natural-background-radiation dose. An average individual in the general public will receive 5 rem of whole-body dose over 50 years from natural radioactive sources (NCRP, 1975). The maximum whole-body dose commitment received by an individual from the most severe accident scenario is 1.1 rem, which is only 22% of the 50-year natural-background dose he would receive to the whole body. The bone and lung dose commitments from the tables can also be compared with background values. The average annual dose rates from natural-background sources are approximately 100 mrem to the bone and 180 mrem to the lungs (NCRP, 1975). As an indication of the significance of the bone and lung dose commitments in the tables, the bone dose should be compared directly to the 5 rem received as a 50-year dose from natural background, and the lung-dose commitment should be compared to the 9 rem received by the lung from natural radiation.

The population dose commitments in Tables 6-14 and 6-15 represent the sum of the dose commitments received by all individuals affected by the dispersion of the radioactive material.

The results of the four hypothetical accidents considered here would require a compounding of unlikely circumstances which make these spectacular accidents relatively unimportant compared with other hazards to which the public is exposed. From the shipping data and accident rates discussed

Table 6-14. Dose to a Small Urban Area[a]

Scenario	Dose commitment (man-rem)		
	Bone	Lung	Whole body
CH TRU rail	1700	83	40
CH TRU truck	2000	99	48
RH TRU	0.1	0.024	0.090
Spent fuel	4200	1000	3700

[a]Approximately 6000 people are affected by the plume.

Table 6-15. Dose to a Large Urban Area[a]

Scenario	Dose commitment (man-rem)		
	Bone	Lung	Whole body
CH TRU rail	3700	190	90
CH TRU truck	4500	220	110
RH TRU	0.22	0.052	0.20
Spent fuel	9400	2300	8300

[a]Approximately 105,000 people are affected by the plume.

earlier, the number of accidents of all types were calculated. Only 0.5% of truck accidents and 0.4% of rail accidents will encounter impacts as severe as those assumed here. As indicated in Table 6-12, the occurrence of fire in accidents is even less likely. When account is taken of the probability that an accident may occur (1) in an urban area and at this severity (30%), (2) under F stability conditions (approximately 20%), and (3) with the wind in the direction of greatest population (6%), the results shown in Table 6-16 are obtained. Since many parameters (such as plume size, cloud height, packaging damage, and population densities), have been selected conservatively, the data in Table 6-16 should be considered upper limits to the probability of the occurrence of the given accidents.

Table 6-16. Approximate Frequency of Hypothetical Accidents

Hypothetical accident	Frequency (occurrences per year)		
	All accidents	Accidents of stated severity	Accidents under conditions indicated in text
CH TRU (rail)	5.9	0.024	8.6×10^{-5}
CH TRU (truck)	1.2	0.0012	4.3×10^{-6}
RH TRU (rail)	0.82	0.0016	5.8×10^{-6}
Spent fuel (rail)	0.27	0.00054	1.9×10^{-6}

The existing licensing requirements for radioactive-material packages provide very high protection levels, and the regulatory test environments are much more severe than the vast majority of transportation accidents. The preceding scenario analysis was performed for accidents whose effects are even more severe than those protected against by the existing regulations. The potential radiation doses to the general public from transportation accidents are small, and the likelihood that such severe accidents will occur at all is nearly zero.

6.8 INTENTIONAL DESTRUCTIVE ACTS

In addition to the normal and accident environments that could occur in transit, there is the possibility of intentional destructive acts directed at WIPP shipping systems and containers. Various aspects of this potential problem have been described in NUREG-0170 (NRC, 1977) and by DuCharme (1978). The conclusion to be drawn from these studies is that, even when subjected to intentionally destructive acts, the dispersed radioactive materials will not produce a significant environmental impact because packaging regulations key the level of protection to the potential hazards of the contents. Thus, packages containing small quantities of radioactive materials are easier to breach than a package of spent fuel. Moreover, the studies show relatively limited consequences--even in areas of very high population densities--from hypothetical releases of spent fuel resulting from extraordinary acts. For shipments to the WIPP reference repository, intentional acts will not produce consequences more significant than the accident consequences calculated in Section 6.7.

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7 The Reference Site and Environmental Interfaces

This chapter begins with a brief general description of the reference site in southeastern New Mexico. It then discusses in some detail the two environmental sciences of principal concern to a repository for nuclear wastes: geology and hydrology. It concludes with a discussion of the archaeological resources at the site. Detailed descriptions of the demographic, socioeconomic, climatic, and ecological characteristics of the site and surrounding area are presented in Appendix H.

7.1 GENERAL DESCRIPTION

The reference site is in Eddy County, New Mexico about 25 miles east of Carlsbad. Its area is 18,960 acres, all Federal and State land.

The site (Figure 7-1) is monotonous in aspect and covered with desert vegetation. Ranching is the characteristic activity, and cattle are often to be seen. Ranch buildings are many miles apart; in between one sees an occasional windmill, stock-watering tank, drilling rig, or grasshopper pump. There are many roads in the area, the better ones surfaced with caliche, the poorer ones often little more than tracks in the sand. The most noticeable features are the potash-mining operations, especially the processing plants with their very large buildings and stacks. Their emissions often create a haze heavy enough to block the view of the mountains 40 to 60 miles to the west.

Thirteen people live within 10 miles of the proposed site; about 94,000 people live within 50 miles, mainly in seven municipalities: Artesia, Carlsbad, and Loving in Eddy County and Eunice, Hobbs, Jal, and Lovington in Lea County. The closest of these are Loving and Carlsbad, 18 and 26 miles away, respectively; the largest are Carlsbad and Hobbs, with 25,500 and 31,300 inhabitants, respectively.

The basic industries of the area are mining, manufacturing, and agriculture. Mining is the major industry in both counties, accounting for 22.2% and 27.3% of the personal income generated in Eddy and Lea Counties, respectively. In Eddy County, mining is centered on potash; in Lea County, it is centered on oil and gas. Manufacturing (36 companies in Eddy County and 48 companies in Lea County) accounted for 5.2% of all personal income generated in the two-county area in 1976. Agriculture, which produces principally meat animals and livestock in the two-county area, contributed less than 5% of the total personal income. Within 10 miles of the site, agriculture is restricted to cattle grazing.

Tourism also contributes substantially to the economy of the two-county area, particularly in Eddy County. The main tourist attraction in the area is Carlsbad Caverns National Park, which is approximately 22 miles southwest of Carlsbad and 41 miles west-southwest of the site. In 1977 it received 862,790 visitors, or nearly 44% of the visitors to all 11 national parks and monuments throughout the State. Other nearby parks (Guadalupe Mountains National Park, Living Desert State Park, the Presidents' Park in Carlsbad, and others) also attract local residents and tourists. Outdoor recreation centers around hunting, four-wheel-vehicle driving, and camping.

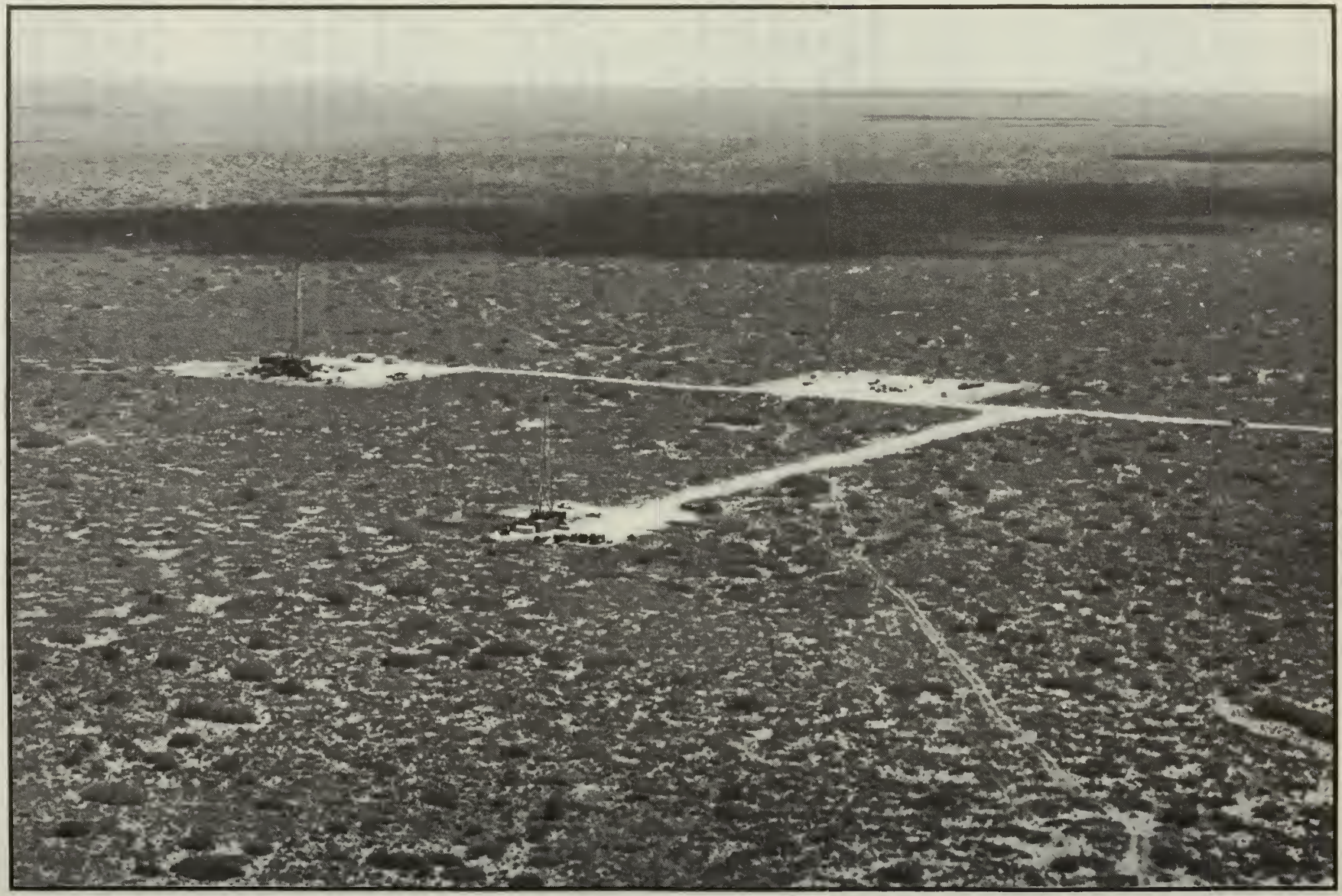

Figure 7-1. View of the WIPP reference site.

Portions of New Mexico Highways 31 and 128 lie within 10 miles of the reference site, and U.S. Highway 62-180 runs east to west about 10 miles north of the site.

Railroad transportation in Eddy and Lea Counties is provided by the Atchison, Topeka and Santa Fe Railroad and the Texas-New Mexico Railroad. The former connects the communities of Loving, Carlsbad, and Artesia in Eddy County. A spur line to a nearby potash mine offers the closest access to the site. The proposed extension of this spur will connect the site with the Atchison, Topeka and Santa Fe line.

The climate of the region is semiarid, with generally mild temperatures, low precipitation and humidity, and a high evaporation rate. Winds are most commonly from the southeast and moderate. In the winter and spring there are occasionally strong west winds and dust storms. During the winter, the weather is dominated by a high-pressure system often situated in the central portion of the Western United States and a low-pressure system commonly located in north-central Mexico. During the summer, the region is affected by a low-pressure system normally situated over Arizona.

Temperatures are moderate throughout the year, although seasonal changes are distinct. Mean annual temperatures in southeastern New Mexico are near 60°F (Eagleman, 1976). In the winter (December through February) nighttime lows average near 23°F and average maximums are well up in the 50s. The lowest recorded temperature at the nearest first-class weather station in Roswell was -29°F, in February 1905. In the summer (June through August), the temperature is above 90°F approximately 75% of the time. The highest recorded temperature at Roswell was 110°F, in July 1958.

Precipitation is light and unevenly distributed throughout the year, averaging 11 to 13 inches. Winter is the season of least precipitation, averaging less than 0.6 inch of rainfall per month. Snow averages about 5 inches per year and seldom remains on the ground for more than 1 day at a time because of the typically above-freezing temperatures in the afternoon. Approximately half the annual precipitation comes from the frequent thunderstorms in June through September. Rains are usually brief but occasionally intense when moisture from the Gulf of Mexico spreads over the region.

The vegetation at the site and in the vicinity consists of native scrubland. The dominant plants at the site are sagebrush, mesquite, muhly grass, dropseed, three-awn, and yucca.

About 70 species of animals representing seven mammalian orders may occur in the region of the site. Few are restricted to a specific habitat. Of these, the desert cottontail, black-tailed jack rabbit, northern grasshopper mouse, southern plains woodrat, porcupine, and coyote are observed in all habitats on and near the site; the only big-game species is the mule deer.

Eighty species of birds have been observed on and near the site. The most common are scaled quail, mourning dove, mockingbird, loggerhead shrike, pyrrhuloxia, black-throated sparrow, western meadowlark, lark bunting, vesper sparrow, Cassin's sparrow, and white-throated sparrow.

Amphibians are not an important part of the regional fauna because suitable habitat is limited.

The area is semiarid, and away from the river aquatic habitats are limited to intermittent streams and livestock-water ponds. Poor water quality is characteristic of much of the Pecos River basin in the lower sections. Both surface water and groundwater are contaminated with salt from natural sources (salt springs, brine seeps, or gypsum overburden) and from human activities (irrigation return flows and potash mining). An important natural source of salt is the concentrated brine springs at Malaga Bend. These sources progressively concentrate salts downstream.

Seasonally wet, shallow lakes (playas) are also common, and many of them are salty. Permanent salty lakes also occur in the area.

There are no permanent surface waters at the site. There may, however, be ephemeral surface waters in land depressions during thunderstorm periods. These provide minimal habitat for aquatic biota. Surface waters in the vicinity are limited to watering livestock.

No species of fish are known to occur closer to the site than the Pecos River.

No plants proposed for the Federal list of endangered or threatened species have been observed near the site, and the lack of suitable habitat makes their occurrence at the site unlikely.

Of the endangered terrestrial vertebrates that have been observed in the region, most are associated with habitats that are not present at or near the site. There are only two species on the Federal list of endangered species that may occasionally be present near the site; they are the bald eagle and the peregrine falcon.

7.2 GEOLOGY

The geologic studies at and around the reference site are aimed at collecting detailed geologic information for use in evaluating the site's suitability with respect to safety and environmental impact. This section summarizes the large amount of geologic information currently available; most has been drawn from the WIPP Geological Characterization Report (Powers et al., 1978), which should be referred to for more detailed information and for references to primary sources.

The geologic characterization of the site started with surveys of literature and existing data and continued with the collection of new data. Many standard petroleum- and mineral-industry techniques have been used to characterize the site. Special emphasis has been placed on correlating data obtained by geophysical techniques and borehole drilling. The geophysical techniques most widely used have been seismic reflection and resistivity. By February 1979, new seismic reflection data for about 75 line-miles had been obtained and over 9000 resistivity measurements had been made and analyzed. Twenty-one boreholes had been drilled to evaluate potash resources. Ten stratigraphic boreholes had been drilled on or near the site, and two other holes had been drilled well away from the site to study salt dissolution. Two of these holes were drilled through the salt to test deep aquifers and to acquire geologic data on the deeper strata.

Geologic studies continue in order to permit a better quantification of the rates of geologic processes in and near the site and to develop a more thorough understanding of the geologic phenomena of interest. More detailed descriptions of geologic, hydrologic, and geophysical methods of investigation are given in Appendix J and in the Geological Characterization Report (Powers et al., 1978).

7.2.1 Summary

The site is a topographically monotonous, slightly hummocky plain covered with caliche and sand. It is near a drainage divide almost free of drainage patterns but separating two major and actively developing solution-erosion features.

The underground storage facilities of the WIPP reference repository are to be near the middle of a 3600-foot-thick sequence of relatively pure evaporite strata containing primarily rock salt and anhydrite, at depths of 500 to 4100 feet beneath the surface. The Salado Formation, richest in rock salt and nearly 2000 feet thick, contains the salt layers in which the facilities are to be constructed at depths of nearly 2100 and 2700 feet. The storage horizons are isolated by at least 1300 feet of undisturbed evaporites, mainly rock salt, above the upper level, and an equivalent thickness of anhydrite and rock salt between the lower level and the underlying nonevaporite formations.

The Delaware basin, in which the site is located, has long been, and is considered still to be, tectonically stable. Major tectonic activity and basin subsidence ended about 225 million years ago; since then regional eastward tilting has been the main activity near the site. No surface faulting is known at the site.

Tectonic faulting and warping of pre-Permian rocks near the site seem to have predated Permian evaporite deposition. Deformation related to salt flow has occurred primarily in the Castile Formation beneath the Salado and is most intense in a belt on the inner edge of the buried Capitan reef 8 miles north of the site. Penetration into thickened salt sections and salt-flow structures in the Castile has occasionally been accompanied by artesian brine flows. No such features have been found at the site. The site appears to be in a slight structural saddle.

Bedded-salt dissolution is restricted to the Rustler Formation and the top of the Salado Formation. There is no evidence that the resulting settlement has produced any significant structural irregularities or collapse features in overlying strata. The closest area affected by dissolution is Nash Draw, whose edge is 4 miles northwest of the site center. The rocks exposed there are strongly jointed, cavernous, and locally brecciated. However, no "breccia pipes" or domes are known at the site.

Minor igneous activity, in the form of dikes and possible sills, has occurred in the Delaware basin, but the closest such feature is about 9 miles northwest of the center of the site and is 35 million years old.

Historical records before 1962 indicate that no earthquakes with a Modified Mercalli (MM) intensity of V or greater have occurred within 120 miles of the site. The closest were two MM IV events at Carlsbad in 1923 and

1949. The strongest within 180 miles was the 1931 MM VIII event at Valentine, Texas, about 125 miles away. The closest shock reported since 1962 (when more and improved instruments were introduced in New Mexico) was a magnitude 3.6 event on November 28, 1974, about 25 miles northwest of the site; the largest was a magnitude 4.6 earthquake centered almost 180 miles to the southwest.

The earthquake data show two distinct clusters. Many small events are scattered on the Central Basin platform, just across the New Mexico-Texas border to the east; these are probably caused by oil-recovery activities. A second cluster is southwest of the site in the Rio Grande rift zone, also outside the Delaware basin in Texas. The remaining recorded earthquakes within 180 miles are scattered sparsely in the Great Plains and the Basin and Range provinces to the north and west.

Analysis of risk from vibratory ground motion at the surface shows that the 1000- and 10,000-year accelerations are less than or equal to 0.06g and 0.1g, respectively. The probabilities of higher values depend mainly on assumptions about the seismic potential of the area near the site.

Mineral resources at the site include caliche, gypsum, salt, sylvite, langbeinite, oil, gas, and distillate. Only potassium salts (sylvite and langbeinite), which occur in strata above the repository, and hydrocarbons (oil, gas, and distillate), which occur in strata below the repository, are of present economic concern. Enormous deposits of caliche, salt, and gypsum off the site are more than adequate for future requirements. To a large extent the other mineral resources lie in control zone IV, in which mining and drilling may eventually be allowed. Langbeinite, gas, and distillate are the only known economic resources that remain under control zones I-III.

The site soils are all from the Kermit-Berino Association--sandy, deep soils from wind-worked mixed sand deposits. The Berino and the Kermit are the only series in control zones I and II; both are deep, noncalcareous, yellow-red, red, or light-colored sands. They occur on gently sloping terrain and have a slight water-erosion potential and a very high wind-erosion potential. Chemical analyses suggest they are typical of nonirrigated, semiarid soils and have no unusual chemical properties.

7.2.2 Regional Geology

This section discusses the surface and subsurface geology of the region within 200 miles of the reference site in southeastern New Mexico, focusing on the Delaware basin.

Geologic history

The geologic history of the region (Figure 7-2) falls into three phases after the formation of a basement crystalline complex 1 to 1.5 billion years ago. The first phase, lasting at least 500 million years, was the uplift and erosion of Precambrian sedimentary and metamorphic rocks. The deep igneous rocks were exposed, and the area was reduced to a nearly level plain (Powers et al., 1978, pp. 3-38ff).

The second phase, corresponding to the Paleozoic Era, was an almost continuous marine submergence of about 225 million years, with slow accumu-

ERA	PERIOD	EPOCH	YEARS DURATION	YEARS BEFORE THE PRESENT	MAJOR GEOLOGIC EVENTS—SOUTHEAST NEW MEXICO REGION
CENOZOIC	Quaternary	Holocene	To Present		– Eolian and erosional/solution activity. Development of present landscape.
		Pleistocene	1,000,000		– Deposition of Ogallala fan sediments. Formation of caliche caprock.
	Tertiary	Pliocene	12,000,000	1,000,000	– Regional uplift and east-southeastward tilting; Basin-Range uplift of Sacramento and Guadalupe-Delaware Mountains.
		Miocene	12,000,000		
		Oligocene	11,000,000		– Erosion dominant. No Early to Mid-Tertiary rocks present.
		Eocene	22,000,000		
		Paleocene	5,000,000	63,000,000	– Laramide "revolution." Uplift of Rocky Mountains. Mild tectonism and igneous activity to west and north.
MESOZOIC	Cretaceous		72,000,000		– Submergence. Intermittent shallow seas. Thin limestone and clastics deposited.
				135,000,000	
	Jurassic		46,000,000		– Emergent conditions. Erosion, formation of rolling terrain.
				181,000,000	– Deposition of fluvial clastics.
	Triassic		49,000,000		– Erosion. Broad flood plain develops.
				230,000,000	
PALEOZOIC	Permian		50,000,000		– Deposition of evaporite sequence followed by continental red beds.
					– Sedimentation continuous in Delaware, Midland, Val Verde basins and shelf areas.
	Pennsylvanian		30,000,000	280,000,000	– Massive deposition of clastics. Shelf, margin, basin pattern of deposition develops.
				310,000,000	
	Mississippian		35,000,000		– Regional tectonic activity accelerates, folding up Central Basin platform, Matador arch, ancestral Rockies.
					– Regional erosion. Deep, broad basins to east and west of platform develop.
	Devonian		60,000,000	345,000,000	– Renewed submergence.
					– Shallow sea retreats from New Mexico; erosion.
					– Mild epeirogenic movements. Tobosa basin subsiding. Pedernal landmass and Texas Peninsula emergent, until Middle Mississippian.
	Silurian		20,000,000	405,000,000 425,000,000	
	Ordovician		75,000,000		– Marathon—Ouachita geosyncline, to south, begins subsiding.
					– Deepening of Tobosa basin area; shelf deposition of clastics, derived partly from ancestral Central Basin platform, and carbonates.
				500,000,000	
	Cambrian		100,000,000		– Clastic sedimentation – Bliss sandstone.
				600,000,000	– Erosion to a nearly level plain.
PRECAMBRIAN					– Mountain building, igneous activity, metamorphism, erosional cycles.

Figure 7-2. Major geologic events affecting southeastern New Mexico and western Texas.

lations of shelf and shallow basin sediments. The early to middle Paleozoic Era was characterized by generally mild epeirogenic movements (vertical movements on a continental scale) and marine carbonate and clastic (sand, silts, and clays) deposition. During the Early Ordovician, a broad sag, the Tobosa basin, formed and began deepening. The deposition of shelf clastics continued, and carbonates was deposited in shallow waters. Mild tectonic activity continued until the middle Mississippian with occasional minor folding and perhaps faulting. As the basin subsided, the Pedernal landmass to the north emerged and there was some regional erosion (Powers et al., 1978, pp. 3-89ff).

From Late Mississippian through Pennsylvanian time, tectonic activity increased; the Central Basin platform, the Matador arch, and the ancestral Rockies formed, with massive deposition of clastics next to the uplifted areas. The Tobosa basin was split into the rapidly subsiding Delaware, Midland, and Val Verde basins. During Pennsylvanian time, repeated marginal faulting caused periodic uplift of bordering platforms and some warping in the Delaware basin. By Early Permian time, this tectonic activity apparently died out as basin subsidence and sedimentation accelerated. Reefs developed during

the mid-Permian; eventually the Permian sea became shallow and briny, forming thick late-Permian evaporite deposits (Castile, Salado, and Rustler Formations) on a vast brine flat. The clastic and evaporite sequence is the result of the rapid accumulation of over 13,000 feet of sediments in a relatively brief period (50 to 75 million years). The final event of this long, nearly continuous accumulation of marine sediments was the deposition of marine or brackish tidal-flat red beds over the evaporite strata (Powers et al., 1978, pp. 3-93ff).

In the third and present phase, which began some 225 million years ago, the region emerged from marine conditions and returned to relatively stable tectonic conditions. During the Triassic, a broad flood-plain surface developed, followed late in the period by the deposition of clastics and the formation of a rolling terrain. During the Cretaceous, the area was submerged, and thin limestone and clastics collected in intermittent shallow seas. During the Jurassic, and perhaps as early as the Triassic, subsurface dissolution of the Upper Permian evaporites began. At the close of the Mesozoic the Rocky Mountains were uplifted, with mild tectonic and igneous activity to the west and north of the site. Throughout most of the Tertiary, erosion dominated. Mid- to late-Tertiary Basin and Range uplift of the Sacramento and Guadalupe-Delaware Mountains was accompanied by regional uplift and east-southeastward tilting. Miocene-Pliocene Ogallala fan deposits accumulated on this gently sloping surface, and a resistant caliche caprock formed. During Quaternary time, the present landscape developed through surface erosion and dissolution of the Upper Permian evaporites, terrace and stream-valley deposition, and the deposition of wind-blown material (Powers et al., 1978, pp. 3-89ff).

During the third phase, periods of continental deposition have alternated with erosional episodes marked by angular unconformities. These unconformities represent intervals during which the salt beds at the site were tilted and subjected to potential dissolution. At least four erosional episodes are recognized:

1. Early Triassic time, in which the Dewey Lake Red Beds were eroded to a slight angular unconformity before deposition of the Upper Triassic Santa Rosa and Chinle Sandstones.

2. Jurassic-Early Cretaceous time, in which the Santa Rosa was tilted and eroded to a wedge before marine inundation in Washitan time (latest Early Cretaceous).

3. A Late Cretaceous through mid-Tertiary interval when the region was again tilted and the Triassic Santa Rosa Sandstones were beveled for a second time.

4. A post-Ogallala uplift and erosion in early Pleistocene time, before deposition of the (Kansan?) Gatuna took place.

After the deposition of the Gatuna Formation, there probably were wetter intervals corresponding to the later Illinoian and Wisconsin glaciations during which there was renewed erosion.

Each period of tilting and erosion allowed salt migration along the resultant slope. The salt deformed as it impinged on reef abutments or responded to uneven sediment loading or erosional unloading. There may have been

several such episodes. Furthermore, each erosional period subjected buried salt to potential dissolution. Any present "deep dissolution" features could have started as soon as Early Triassic time, but more probably all episodes of active dissolution occurred during the Jurassic and Late Cretaceous-mid Tertiary and the several pluvial periods corresponding to Pleistocene glacial stages. Attempts to reconstruct the history of salt dissolution and to predict its future must consider that dissolution was episodic. There is no sign that the present dissolution is any more rapid than that in the geologic past. Detailed mapping studies are under way that will clarify dissolution rates at various times in the geologic history of the site.

Physiography and geomorphology

The site proposed for the WIPP reference repository is in the Pecos Valley section of the southern Great Plains physiographic province, a broad highland belt sloping gently eastward from the Rocky Mountains and Basin and Range province to the Central Lowlands province (Figure 7-3). The Pecos Valley section itself is dominated by the Pecos River valley, a long north-south trough 5 to 30 miles wide and as much as 1000 feet deep in the north. The valley has an uneven rock- and alluvium-covered floor with widespread solution-subsidence features, the result of dissolution in the underlying Upper Permian rocks. The terrain varies from plains and lowlands to rugged canyonlands, including such erosional features as scarps, cuestas, terraces, and mesas. The surface slopes gently eastward, reflecting the underlying rock strata. Elevations range from over 6000 feet in the northwest to about 2000 feet in the south (Powers et al., 1978, pp. 3-3ff).

The Pecos Valley section is bordered on the east by the Llano Estacado, a virtually uneroded plain formed by river action. The Llano Estacado is part of the High Plains section of the Great Plains physiographic province. Few and minor topographic features are present in the High Plains section, formed when over 500 feet of Tertiary silts, gravels, and sands were laid down in alluvial fans by streams draining the Rocky Mountains. In many areas the nearly flat surface is cemented by a hard caliche layer.

To the west of the Pecos Valley section are the Sacramento and the Guadalupe Mountains, part of the Sacramento section of the Basin and Range province. The Capitan escarpment along the southeast side of the Guadalupe Mountains marks the boundary between the Basin and Range and the Great Plains provinces. The Sacramento section has large basinal areas and a series of intervening mountain ranges.

The main geomorphic features bearing on the region are the Pecos River drainage system, the Mescalero Plain, karst terrain, and wind-erosion "blow-outs." The Pecos River system has evolved from the south, cutting headward through the Ogallala sediments and becoming entrenched sometime after the Middle Pleistocene. It receives almost all the surface and subsurface drainage of the region; most of its tributaries are intermittent because of the semiarid climate. Most of the ground surface east of the Pecos River valley lies in the Llano Estacado, a poorly drained eastward-sloping surface covered by gravels, wind-blown sand, and caliche that has developed since early to middle Pleistocene time. The surface locally has a karst terrain containing superficial sinkholes, dolines, and solution-subsidence troughs, from both surface erosion and subsurface dissolution. The site lies near a caliche- and sand-covered drainage divide separating two major and actively developing solution-erosion features: Nash Draw to the west and San Simon Swale to the east.

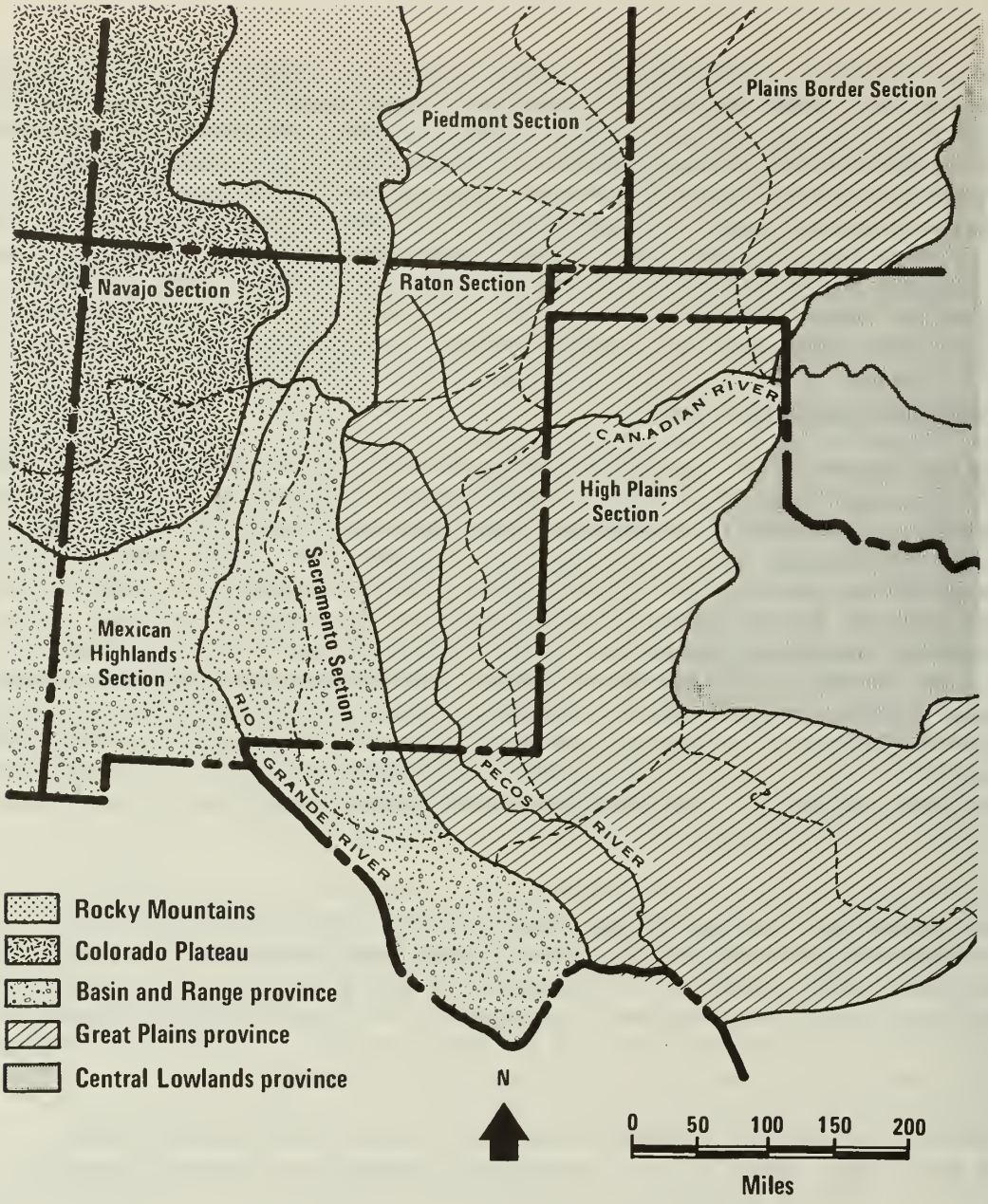

Figure 7-3. Physiographic provinces and sections.

Stratigraphy and lithology

A regional geologic section is shown in Figure 7-4. The known stratigraphic section at the site region includes Precambrian through Triassic rocks, overlain by outliers of possible Cretaceous age and widespread sediments of late Tertiary through Quaternary age.

Metasediments and granitic-volcanic igneous materials constitute the majority of the regional basement, cropping out in isolated areas to the west and north. The granitic rocks range in age from about 1400 million years in the north to about 1000 million years in the south and are overlain in places by younger volcanic terrains. The surface of the Precambrian reflects the late Paleozoic platform-and-basin structural configuration of the area (Powers et al., 1978, pp. 3-24ff).

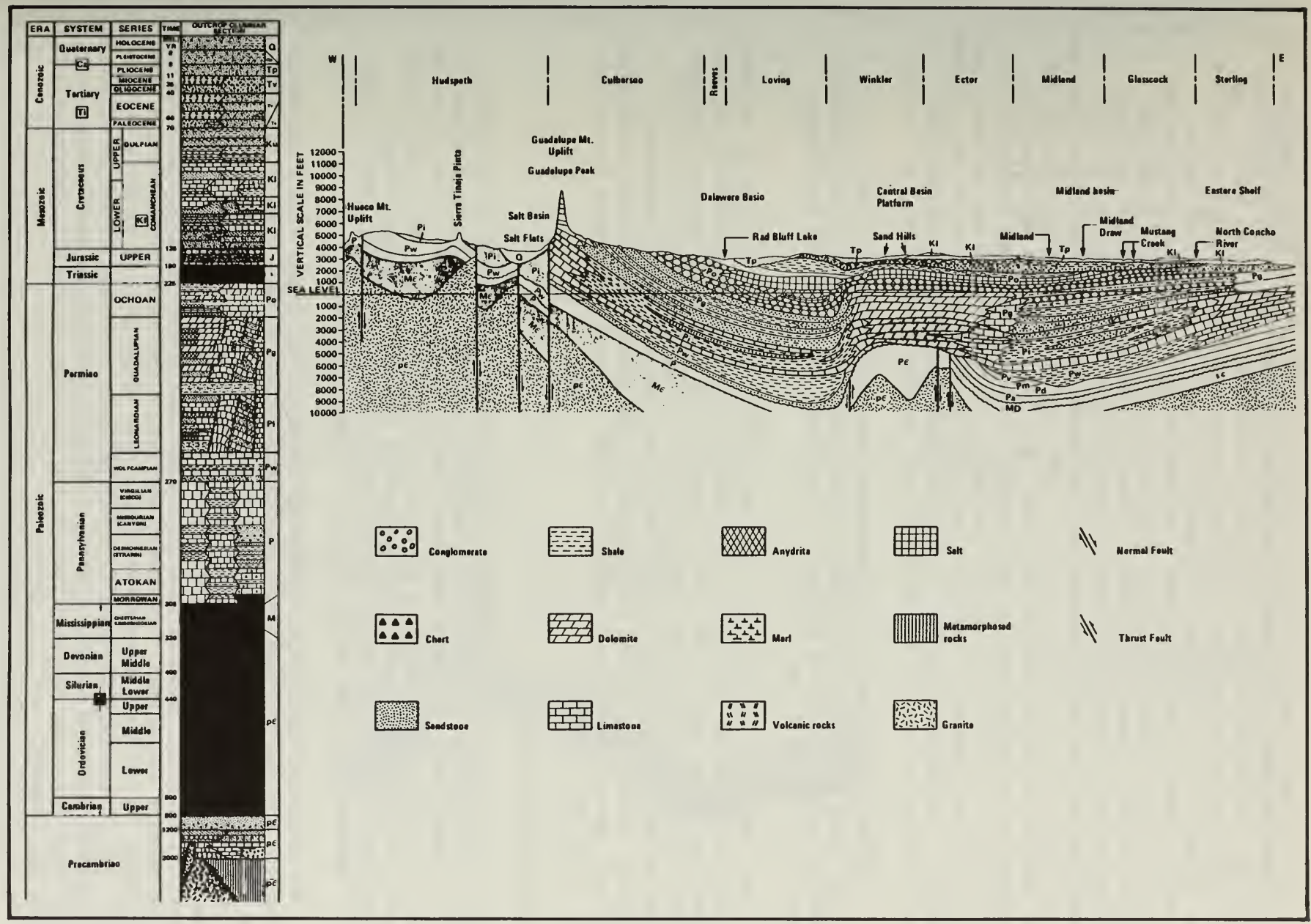

Figure 7-4. Geologic column and cross section of the New Mexico-Texas region.

The Paleozoic section consists of up to 20,000 feet of Upper Cambrian sandstones through Upper Permian evaporites and red beds. The Ordovician, Silurian, and Devonian rocks are mainly carbonates with sands, shales, and cherts deposited in shallow, calm shelf areas of broadly subsiding areas of the Tobosa basin, with minor influence from uplifted areas such as the ancestral Central Basin platform. The Mississippian sequence consists of locally cherty limestones overlain by silty and sandy shales, truncated against adjacent emerging uplands. Post-Mississippian mountain building caused uplift, tilting, and erosion, producing a massive section of Lower Pennsylvanian continental sediments interbedded with dark limestones, particularly toward the top of the section. From late in the Pennsylvanian through the Permian, a basin, basin-margin, and shelf configuration developed that resulted in the deposition of dark shales, clastics, and some limestones and bioclastics. During the Permian a series of reefs formed along the basin margins, and shallow-water limestones and clastics were deposited on the adjacent shelves. In the Late Permian, evaporites were deposited in shallow seas restricted by the encircling Permian reefs (Powers et al., 1978, pp. 3-27ff).

The Mesozoic sequence is represented only by the Upper Triassic terrigenous Santa Rosa Sandstone, which in many places is truncated or removed by erosion, and by scattered patches of Cretaceous limestone and sandstones (Powers et al., 1978, pp. 3-53ff).

The lower Cenozoic section is missing from the region because it has been eroded or was never deposited. The widespread late Miocene-Pliocene Ogallala Formation to the east of the site represents the earliest preserved Cenozoic deposit known in the region. The Ogallala is capped by a dense, resistant layer of caliche, probably formed during the late Pliocene. Quaternary deposits occur only locally and consist of the middle Pleistocene to Holocene terrace, channel, and playa deposits as well as wind-blown sands (Powers et al., 1978, pp. 3-56ff).

Structure and tectonics

The major structural framework of the region is provided by the large-scale basins and platforms of late Paleozoic age and by Cenozoic features primarily associated with Basin and Range tectonics (Figure 7-5). The principal late Paleozoic features of the area were the Tobosa basin, later the Permian basin and its border lands. These elements include the Delaware basin, Central Basin platform, Midland basin, the Northwestern shelf, Pedernal uplift, Matador arch, Val Verde basin, and Diablo platform.

The Delaware basin is a broad, oval asymmetrical trough with a northerly trend and southward plunge and a structural relief of more than 20,000 feet on top of the Precambrian. Deformation of the basin rocks is minor, with formations older than Late Permian only gently downwarped. Deep-seated faults, some reflecting Precambrian faults, occur--as do folds, joint sets, and a number of smaller, probably solution-related structures originating in the Upper Permian evaporites. The basin was defined by early Pennsylvanian time, with major structural adjustments during Late Pennsylvanian to Early Permian time. Since the Late Permian, tectonic activity has lessened and is expressed in regional eastward tilting, relative uplift resulting in some erosion, and major faulting along the west face of the Guadalupe Mountains (Powers et al., 1978, pp. 3-60ff).

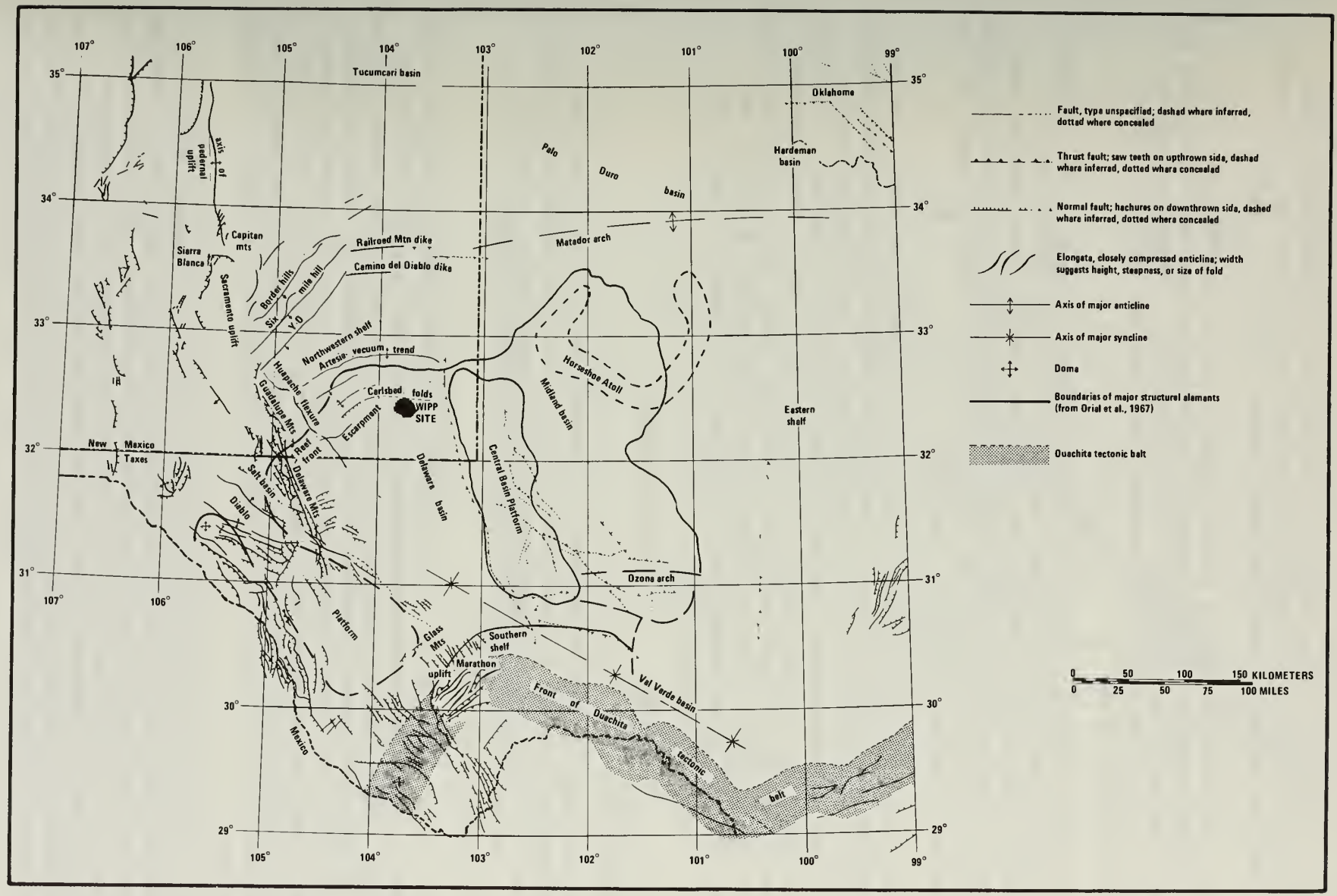

Figure 7-5. Major regional structures.

The Central Basin platform, a northward-trending subsurface feature separated from the Delaware basin to its west by a zone of major normal faulting, represents a broad uplift of Precambrian to Pennsylvanian rocks, within which movement took place periodically, probably from the Precambrian until the late Paleozoic, when the basin became structurally stable.

North and northwest of the Delaware basin lies the Northwestern shelf, which was well developed before Permian time and which may have originated in the Early Paleozoic as the margin of the Tobosa basin. There are various flexures, arches, and faults on the shelf, but tectonic activity probably ceased in Tertiary time.

The Diablo platform, which forms the southwestern border of the Delaware basin, experienced uplift, folding, and faulting in the late Paleozoic. Deformation also occurred in late Tertiary time through block faulting and buckling. Holocene uplift along the eastern side suggests continuing tectonic development in the area. The other late Paleozoic structural elements of the area are only remotely related to the site.

Late Tertiary Basin and Range tectonics produced the Sacramento, Guadalupe, and Delaware Mountains to the west. They are generally eastward-tilted fault blocks bordered on the west by complex normal fault systems forming short, steep westward slopes and backslopes dipping gently eastward. Tectonic activity began during Mississippian to Early Permian time as fault systems, followed by the major Basin and Range tectonics. Small fault scarps in recent alluvium at the western edge of these ranges, some seismic activity, and changes in level lines suggest that structural development is continuing (Powers et al., 1978, pp. 3-73ff).

Igneous activity

Post-Precambrian igneous activity in the region consists of Tertiary intrusives and Tertiary to Quaternary volcanic terrains located on the north, west, and south of the site area outside the Delaware basin. Only minor igneous activity, now represented by dikes and possibly sills, is known to have occurred within the basin.

The closest such igneous feature to the reference site is a near-vertical trachyte or lamprophyre dike or en-echelon dikes trending about N 50° E for perhaps 75 miles into New Mexico from near the Texas-New Mexico border southwest of Carlsbad Caverns, passing about 9 miles northwest of the site center (Figure 7-6). The dike is exposed in two mines. It is also shown by cuttings or logs from drill holes and by aeromagnetic indications, and at the surface 42 miles southwest of the site in the Yeso Hills. It has been dated as Mid-Tertiary and intrudes only into the late Permian Salado and underlying formations.

The principal Tertiary igneous features outside the Delaware basin are possible intrusive bodies within the Delaware Mountains, widespread intrusives farther south and west in the Trans-Pecos region of Texas, and several features well to the north of the basin: the eastward-trending El Camino del Diablo and Railroad Mountain dikes and the stocks of the Capitan and Sierra Blanca Mountains. Quaternary volcanic and related extrusive terrains are present west of the site region within the Basin and Range province.

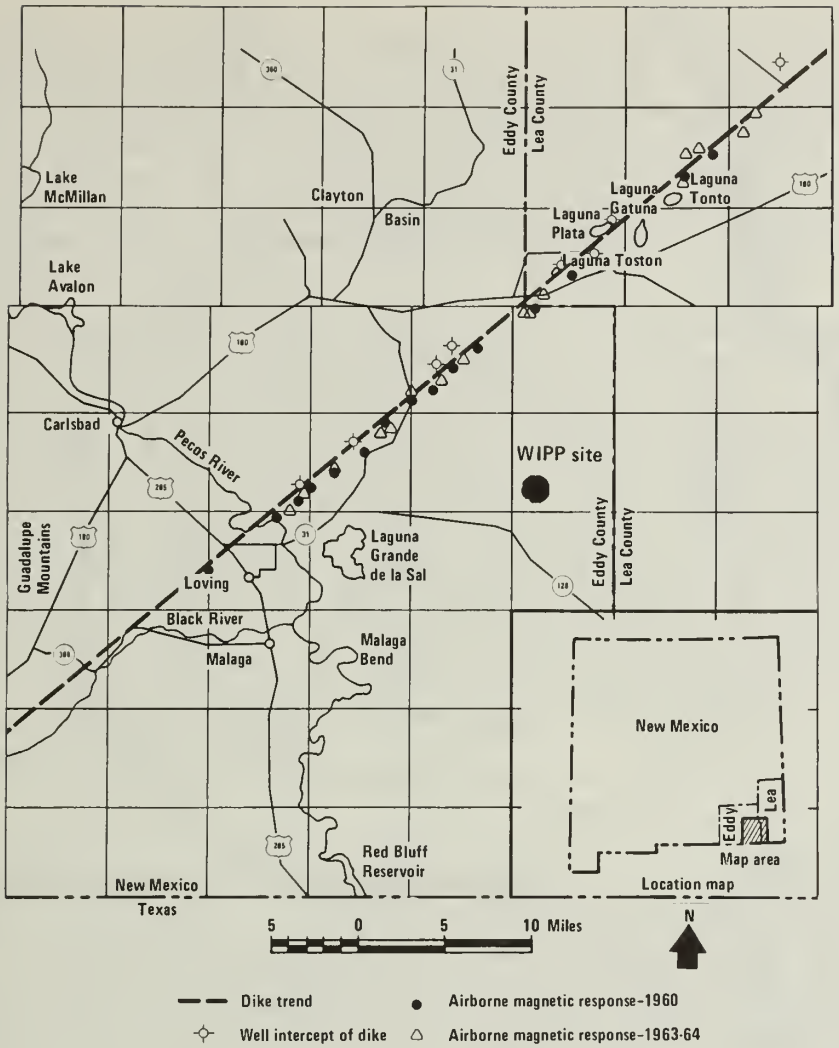

Figure 7-6. Igneous dike in the vicinity of the reference site.

7.2.3 Site Physiography and Geomorphology

The land surface in the area of the reference site is a semiarid, wind-blown plain sloping gently to the west and southwest, hummocky with sand ridges and dunes. A hard caliche layer is typically present beneath the sand blanket and on the surface of the underlying Pleistocene Gatuna Formation. Figure 7-7 is a topographic map of the area. Elevations at the site range from 3570 feet in the east to 3250 feet in the west. The average east-to-west slope is 50 feet per mile (Griswold, 1977).

Livingston Ridge is the most prominent physiographic feature near the site. It is a west-facing escarpment that is about 75 feet high and marks the eastern edge of Nash Draw, the nearest drainage course to the site. Nash Draw is a shallow 5-mile-wide basin, 200 to 300 feet deep and open to the southwest. It is at least partly caused by subsurface dissolution and the accompanying subsidence of overlying materials. Livingston Ridge is the approximate boundary between terrain that has undergone erosion and/or solution collapse and terrain that has not been as significantly affected (Powers et al., 1978, pp. 4-5ff).

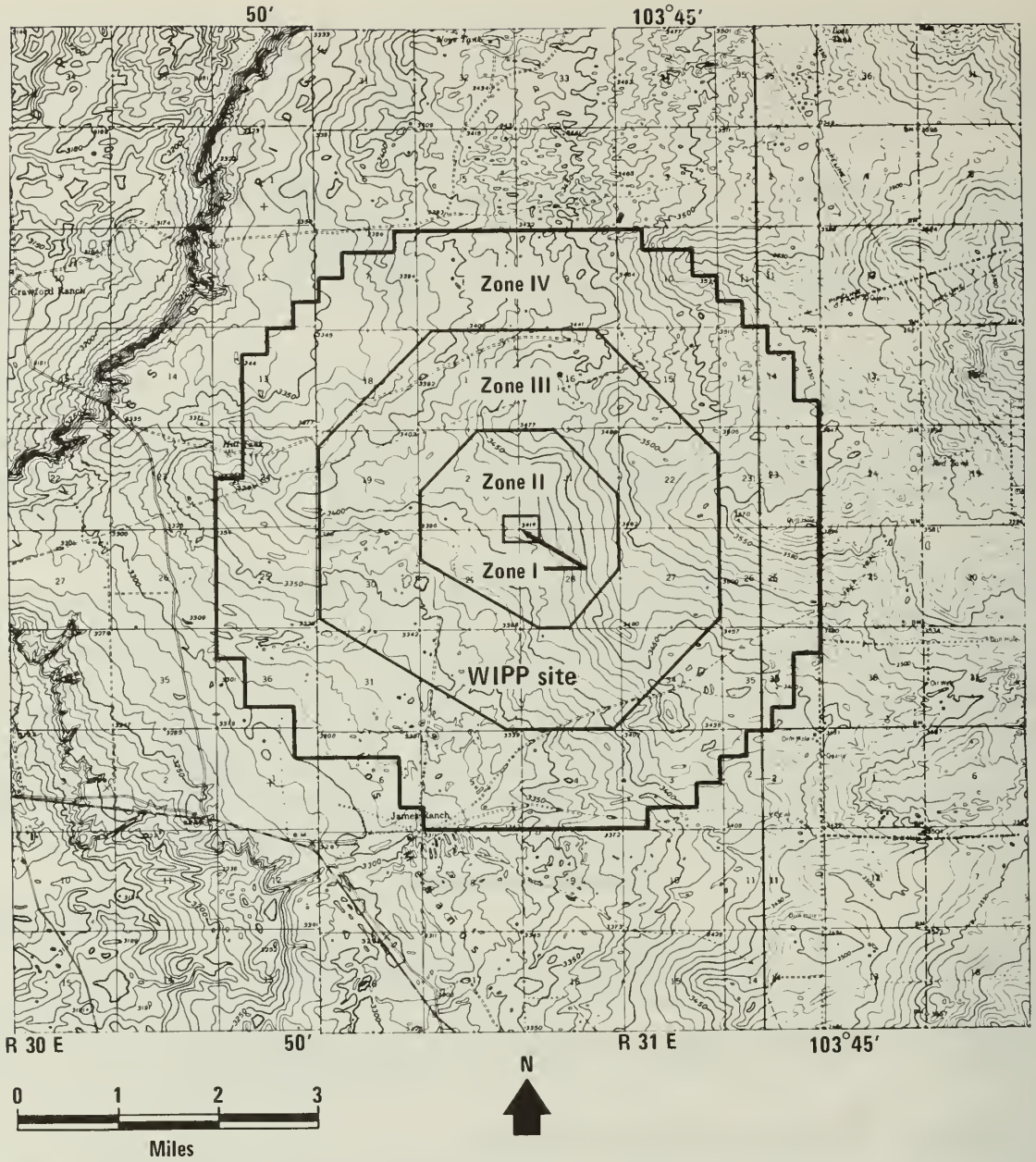

Figure 7-7. Site topographic map.

About 15 miles east of the site is the southeast-trending San Simon Swale, a depression due at least in part to subsurface dissolution. Between San Simon Swale and the site is a broad, low mesa named "The Divide." It is about 6 miles east of the site, about 100 feet above the surrounding terrain, and is a boundary between southwest drainage toward Nash Draw and southeast drainage toward San Simon Swale. The Divide is capped by the Ogallala Formation and overlying caliche, upon which have formed small, elongated depressions similar to those in the adjacent High Plains section to the east.

Surface drainage is intermittent; the nearest perennial stream is the Pecos River, about 15 miles southwest of the site center. Surface runoff from heavy rains at the site may enter the Pecos River via Nash Draw; discharge of

shallow groundwater seems also to be controlled by the Pecos River (see Section 7.3, Hydrology). Basins like Nash Draw have evolved partly by subsurface dissolution of thick salt, but there is no way to estimate the rates of dissolution under different climatic conditions. The site's location near a natural divide protects it from flooding and serious erosion by heavy runoff. Should the climate become more humid, any perennial streams should follow the present basins, and Nash Draw and San Simon Swale would be the most eroded, leaving the divide area relatively intact (Bachman, 1974).

Dissolution-caused subsidence in Nash Draw and elsewhere in the Delaware basin has caused a search for geomorphic indications of subsidence near the site. One feature that has attracted some attention (Griswold, 1977) is a shallow sink about 8 miles north of the site center in the southeast part of Section 9, T 21 S, R 31 E. It is very subdued, about 1000 feet in diameter and a mere 30 feet deep. Resistivity studies (Elliot, 1976) indicate very shallow surficial fill within this sink and no disturbance of underlying beds, indicating a surface, rather than subsurface, origin. Recent resistivity surveys in the site area (Elliot, 1977) showed an anomaly in Section 17, T 22 S, R 31 E, within control zone II. It resembles the pattern over a known sink, a so-called breccia pipe, but drilling showed normal subsurface structure without breccia, and the geophysical anomaly has been accounted for by low-resistivity rock in the Dewey Lake Red Beds. The process of salt dissolution is discussed in Section 7.3.

7.2.4 Site Stratigraphy and Lithology

This section provides stratigraphic (chronologic sequence, age, depth, thickness, and extent) and lithologic (rock type) descriptions of the total rock column at the site. More detail is given in the Geological Characterization Report (Powers et al., 1978, pp. 4-9ff). The site geologic column, Figure 7-8, indicates the major rock units beneath the site. Table 7-1 provides similar information in tabular form. The systems not discussed in the text are not present at the site because of nondeposition or erosion.

The rock column at the site consists of a Precambrian crystalline basement 1400 to 1000 million years old, mostly metasediments and igneous rocks; carbonates of Ordovician to Mississippian age deposited in shallow-water or shelf conditions; basinal sediments of Late Mississipian to mid-Permian age, mostly sandstone deposited after the Delaware basin had formed; Permian evaporites; and Late and post-Permian clastic rocks. The surface is covered by a thin persistent veneer of Holocene sand.

The total thickness of the rock column above the Precambrian basement at the site is about 18,000 feet. Of this, pre-Permian rocks make up about 5000 feet, Permian rocks over 12,000 feet, and post-Permian rocks less than 100 feet. The Permian system constitutes over two-thirds of the sedimentary pile, but the portion of interest for the reference repository is the upper 4000 feet of evaporite and evaporite-related rocks of the Ochoan Series of Late Permian age.

Precambrian

Crystalline basement rocks near the site are believed to be granitic igneous rock or metamorphosed granites and rhyolites. The basement surface is

Figure 7-8. Site geologic column.

Table 7-1. Summary of Reference-Site Stratigraphy

Era	System	Series	Formation	Million years before present	Approx. depth to lower contact at site (ft)	Approximate thickness (ft)
Cenozoic	Holocene		Surficial sand		10	0-100
	Quaternary	Pleistocene	Mescalero caliche	1		
			Gatuna		40	0-35
	Tertiary[a]					
Mesozoic	Cretaceous[a]					
	Jurassic[a]					
	Triassic	Upper Triassic	Santa Rosa Sandstone	181	50	0-250
Paleozoic	Permian	Ochoan	Dewey Lake Red Beds	230	540	100-550
			Rustler		850	275-425
			Salado		2,825	1750-2000
			Castile		4,075	1250
		Guadalupian	Bell Canyon		5,100	1000
			Cherry Canyon		6,200	1100
			Brushy Canyon		8,000	1800
		Leonardian	Bone Springs		11,400	3400
		Wolfcampian	"Wolfcamp"		12,800	1400
	Pennsylvanian	Desmoinesian?		280		
		Derryan?	Strawn		13,100	300
		Morrowan?	Atoka		13,800	650
			Morrow		15,000	1250
	Mississippian	Upper Miss.	Barnett Shale	310		
		Lower Miss.	--		15,600	650
	Devonian	Upper Devonian	Woodford Shale	345	15,800	175
	Silurian	--	--	405	16,900	1150
	Ordovician	--	Montoya Group	425		
			Simpson Group			
			Ellenburger Group		18,200	1300
	Cambrian[a]			500		
Precambrian				600		

[a]Systems not present at the site.

about 17,900 to 18,200 feet deep. Radiometric ages are 1140 to 1350 million years (Powers et al., 1978, p. 4-12).

Pre-Permian rocks

Ordovician system. In the area of the site, the Paleozoic section begins with an estimated 1290 feet of Ordovician rocks beneath the center of the site (Foster, 1974). These rocks consist mostly of carbonates alternating with minor amounts of shale, sandstone, and conglomerate.

Silurian system. Lying above the Ordovician dolomites is carbonate rock of Silurian or Siluro-Devonian age. Near the site it is entirely light-colored dolomite with appreciable chert, except for two prominent intervals of limestone (Foster, 1974). The basal contact is apparently disconformable in this area. The total thickness of Silurian or Siluro-Devonian carbonates is about 1140 feet (Foster, 1974). They thin westward relatively uniformly. The top of the Silurian is about 15,850 feet beneath the surface (Netherland, Sewell, 1974).

Devonian system. The Devonian system is represented by a distinctive unit of organic, pyritic black shale that unconformably overlies the Silurian carbonates. Beneath the center of the site it is about 175 feet thick and thickens gradually southeastward (Foster, 1974).

Mississippian system. Rocks of the Mississippian system at the site include a series of limestones and overlying shale. The top of the Mississippian is about 15,150 feet below the surface (Netherland, Sewell, 1974). The carbonates are about 480 feet thick at the site, gradually thickening northward. The overlying black shale is about 175 feet thick.

Pennsylvanian system. The Pennsylvanian strata at the site are approximately 2200 feet thick (Foster, 1974). The section consists of alternating members of sandstone, shale, and limestone and rests unconformably on the underlying Mississippian shale.

Unlike most of the earlier Paleozoic strata, the Pennsylvanian strata and some of the Lower Permian strata in the Delaware basin show many changes in vertical lithology and many lateral facies changes along time-equivalent horizons.

Permian system

The Permian strata are as much as 13,000 feet thick within the Delaware basin, the most complete Permian succession in North America. The Permian section at the site is about 12,800 feet thick, over two-thirds of the entire sedimentary column and more than twice as thick as all earlier Paleozoic formations combined (about 5200 feet). Of this total, 3600 to 3800 feet of thick, relatively pure evaporites (primarily halite and anhydrite) are in the upper part of the sequence, where the repository is to be constructed (Powers et al., 1978, pp. 4-19ff).

The Lower Permian rocks are interbedded limestone, shale, dolomite, and sandstones. During the Late Permian the Capitan reef and the overlying massive evaporites were deposited. These evaporites consist of, in ascending order, the Castile, Salado, and Rustler Formations, which are overlain by the clastics of the Dewey Lake Red Beds. The four formations at the site have a

total thickness of about 4100 feet, of which almost 3600 feet are evaporites--largely anhydrite and halite, with some fine-grained clastics and evaporitic salts including carbonates and potassium and magnesium minerals. The Castile and Rustler are richer in anhydrite and carbonate rock than is the Salado, and they form barriers that over geologic time have retarded the movement of groundwater into the Salado Formation.

The Castile Formation rests in apparent conformity on underlying sandstones and limestones. At the site its top is about 2800 feet deep, and it is about 1300 feet thick. It consists mainly of massive beds of laminated calcite-anhydrite and halite. In the basin the Castile has several massive anhydrite members separated by moderately thick salt beds merging to the north into a wedge of anhydrite that thins toward the Capitan reef.

The Salado Formation, the principal salt formation of the area, lies unconformably on the Castile. At the center of the site its top is 860 feet deep, and its thickness is 1976 feet. It is divided informally into three main members. The individual beds are very persistent and are the basis of a numbering system used by mining companies. The three members are an unnamed lower, the McNutt Potash Zone, and an unnamed upper. The three members are similar except that the McNutt Potash Zone is locally rich in potassium- and magnesium-bearing minerals and supports extensive potash mining to the west and north of the site. The upper member contains relatively larger amounts of clay minerals and sulfate minerals, including anhydrite and polyhalite (Powers et al., 1978, pp. 4-29ff).

The lower member of the Salado Formation is the proposed location of the reference repository. A hole at the center of the site shows the purest and thickest halite beds to be in this lower member. The lower member consists primarily of halite, though interbeds of anhydrite and polyhalite are fairly common. Thin zones with up to a few percent clay mineral content are present in the lower member as well as in the rest of the Salado. Many of these zones are associated with anhydrite or polyhalite beds. A significant marker bed in the lower member is a 22-foot seam of anhydrite called the Cowden anhydrite. Within the lower member, the halite below the Cowden is the purest and most uniform, as inferred from drilling logs and the core taken from a drill hole at the center of the site (ERDA-9). Next in quality is a halite zone above the Cowden. This has led to the selection of an RH-waste mine level below the Cowden at a depth of about 2700 feet below the surface, and a CH-waste mine level above the Cowden at a depth of about 2100 feet.

During the drilling of a hole near the site (ERDA-6) and occasionally in potash mines, pockets of nitrogen-rich gas have been encountered in the evaporite sequence. Lambert (1978) suggests that this gas was originally dissolved in seawater trapped as fluid inclusions. The evaporites underwent some postdepositional recrystallization about 204 million years ago; during this process some fluid inclusions coalesced, forming pockets of brine and air. The free oxygen is readily scavenged by reducing chemical species, leaving accumulations of nitrogen-enriched gas.

Outcrops of the Rustler Formation in Nash Draw are often disrupted by solution of salt near the surface and form a jumbled mass of gypsum with some dolomite, sandstone, and clays. Eastward, at greater depths, the gypsum in the Rustler gives way to the original anhydrite and minor polyhalite, and the sandstone and claystone give way to sandy and clayey salt. At the center of the site, where its top is 550 feet deep and the formation is 310 feet thick,

the Rustler consists primarily of thick seams of anhydrite (up to 50 feet thick) and siltstones containing halite near the base. It contains two dolomite beds, the Culebra and the Magenta, 720 and 610 feet deep, respectively. Each is about 25 feet thick. The Culebra contains water of varying quality and quantity (see Section 7.3) (Powers et al., 1978, pp. 4-39ff).

The Dewey Lake Red Beds rest unconformably on the Rustler Formation and are the uppermost of the Late Permian and Paleozoic rocks in the Delaware basin. They are reddish-orange to reddish-brown siltstones and fine-grained sandstones. Some beds are structureless, others are horizontally laminated or cross-laminated. According to Vine (1963), they represent the beginning of continuous deposition of detrital sediment following the long period of evaporite deposition in the Delaware basin and adjacent shelf areas of southeastern New Mexico. At the site, they are 63 feet deep and 490 feet thick.

Post-Permian rocks

Triassic system. The Santa Rosa Sandstone of Late Triassic age rests unconformably with sharp lithologic contact on the Dewey Lake Red Beds. Representing a gap between Permian and Late Triassic time, this unconformity indicates a break in deposition perhaps longer than any previous in the region since Mississippian time or even earlier. At the site the Santa Rosa Sandstone is a 9-foot-thick erosional wedge that pinches out just to the west of the site center. Mostly it is cross-stratified, medium- to coarse-grained, gray to yellow-brown sandstone, but it includes conglomerate and reddish-brown mudstone (Powers et al., 1978, pp. 4-44ff).

Quaternary system. The Gatuna Formation of Pleistocene age forms a thin blanket, locally absent, up to 30 feet thick. In spite of its shallow depth below the surface, however, the Gatuna crops out only rarely, being mostly obscured by a thin but persistent veneer of caliche and surficial sand. The nearest mapped outcrops occur along the west-facing slope of Livingston Ridge at the edge of Nash Draw about 4 miles northwest of the center of the site (Figure 7-9). Though the Gatuna is mainly a fine-grained, reddish or brownish friable sandstone, conglomerate lenses and blankets are common regionally. Gatuna time was the most humid Pleistocene stage in southeastern New Mexico, with an age of about 600,000 years (Bachman, 1974; Powers et al., 1978, pp. 4-47ff).

Beneath an obscuring cover of wind-blown sand, most of the site is covered by a hard caliche (a near-surface layer of calcium carbonate). It is 3 to 5 feet thick, light gray to white, and sandy and is said to be the remnant of an extensive soil profile. It formed about 500,000 years ago through successive cycles of dissolution and reprecipitation of carbonates during the dry period after the moist Gatuna time.

Holocene deposits near the site include wind-blown sand, alluvium, and playa deposits (Figure 7-9). The main deposit is the wind-blown sand, locally known as the Mescalero sand (Vine, 1963), that covers nearly all of the site, occurring either as a sheet deposit resting on caliche or as conspicuous dune fields. The sheets are probably no more than 10 to 15 feet thick on the average; the sand dunes may be as high as 100 feet. At many places the sand consists of a compacted, slightly clayey moderate-brown sand up to 1.5 feet thick overlain by loose, light-brown to light-yellowish-gray sand. The dunes appear to be relatively inactive at present, partly stabilized by a sparse plant cover. The widespread deposits of wind-blown sand are indicative of a

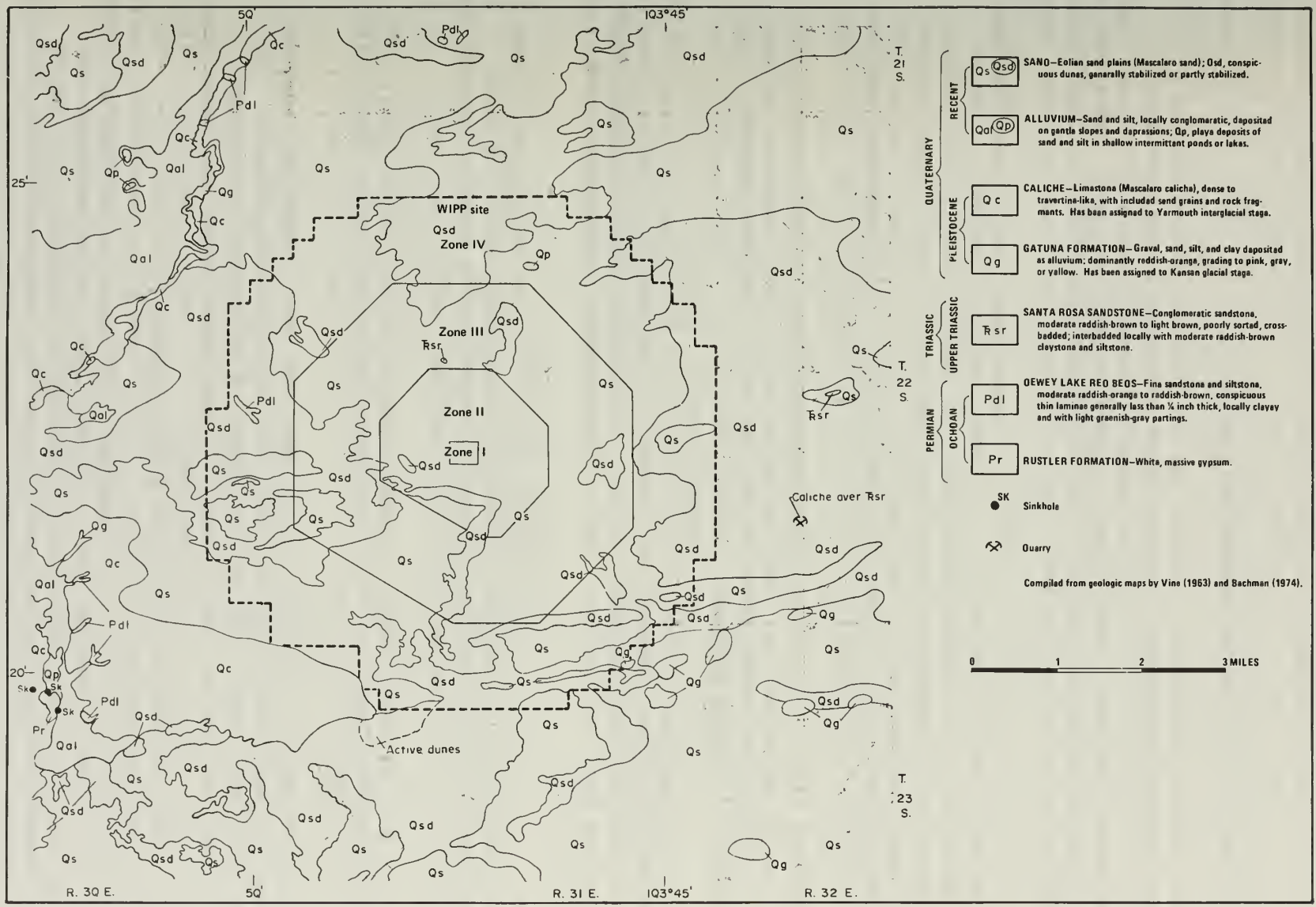

Figure 7-9. Surficial geology map.

large source of fine sand as well as of the extreme fluctuations of climate during Pleistocene time. During humid intervals in Pleistocene time the sand was eroded from nearby outcrops of the Ogallala Formation, and during arid intervals the wind has moved this sand across the Mescalero plain (Bachman, 1974).

Description of the proposed emplacement horizons

The proposed emplacement horizons are at depths of about 2100 and 2700 feet in the Salado Formation. Studies have been made of the mineralogy, chemistry, thermophysical properties, deformation, volatile content, and fluid inclusions of the beds. The Geological Characterization Report (Powers et al., 1978), particularly Chapters 7 and 9, details these studies, studies of related horizons, and methods used.

The physical properties and mechanical behavior of rock salt differ from those of other geologic materials. It shows nonlinear inelastic response under practically all loading conditions. It exhibits ductile-like behavior at temperatures and pressures often encountered in mining. It can undergo large strains before failure, and openings even at very shallow depths have completely closed over long periods (Baar, 1977). It is therefore important to distinguish salt from other rocks, particularly in analyzing deformations.

The rock salt of southeastern New Mexico has been studied through petrography, which gives indirect information on physical and mechanical properties, through direct measurement of physical properties, and through direct measurement of thermal-mechanical properties.

The basic mineral of both repository horizons is halite. Also present are anhydrite, polyhalite, quartz, and a suite of clay minerals (illite, chlorite, talc, serpentine, and expandable clays). Halite beds within the emplacement horizons are about 97% halite. Most of the remainder is anhydrite (Bodine and MacMillan, 1978).

The grain size of all salt studied varies, in order of decreasing abundance, from coarse ($\geq$0.45 inch) to medium (0.05 to 0.45 inch) and fine-grained ($\leq$0.05 inch). The grain geometry of many coarse samples suggests some secondary recrystallization (Bodine and MacMillan, 1978).

Grain boundaries are moderately tight; halite grains touch locally with few mineral constituents in the interstices. Individual grains show no elongation or preferred orientation.

Powdered samples were heated in nitrogen and their weight loss measured. The loss includes water loss, gas loss, and loss from decomposition. The median weight loss was 0.36%, but one sample of polyhalite (theoretically 6 wt% water) from between the proposed storage levels had a 5.4% weight loss (Powers et al., 1978, pp. 7-32ff and Table 7.12). Roedder and Belkin's (1978) samples showed an average of 0.36 wt% fluid throughout the evaporites. The range of fluid content was from about 0.1 to 1.7 wt%, consistent with results obtained by static heating and thermogravimetric analysis. Roedder and Belkin (1978) also indicate that the fluids are not simply sodium and potassium chloride solutions, but include other ions such as magnesium. The amount of gas in the fluid inclusions is generally very low, implying that the inclusion would probably move up a thermal gradient toward a heat source. The inclusions seem not to have migrated significantly since they were formed during Permian time.

The physical properties measured include density, moisture content, porosity, air permeability, electrical resistivity, ultrasonic velocity, and thermal conductivity. Mechanical properties measured include uniaxial compressive strength, unconfined tensile strength, stress-strain behavior and ultimate stress in quasistatic triaxial compression, elastic moduli, principal strain ratios, yield stress (elastic limit), and creep rates. Other tests addressed the effects of specimen preparation on the results obtained in the laboratory. Representative mechanical properties are listed in Table 7-2.

Salt from the site can undergo transient and steady-state creep. Steady-state creep is being considered in design calculations, particularly at high temperatures. Preliminary steady-state creep rates are in the range of 10^{-10} to 10^{-7} sec^{-1}. Transient creep depends on pressure, principal stress difference, and temperature; the results indicate that these three are not independent of each other. Of these three, temperature appears to have the most dramatic effect on the creep rate.

Table 7-2. Properties of Salt at the Reference Site[a]

Property	Average value (range)
PHYSICAL PROPERTIES	
Density (g/cm^3)	2.18
Porosity (%)	0.5 (0.1-0.8)
Moisture loss (% by weight to 300°C)	0.4 (0-1.0)
Resistivity (ohm-m)	58,100 (4900-230,000)
Air permeability (darcys)	10^{-8}
P-wave velocity (km/sec)	4.5 (4.42-4.62)
Thermal conductivity (W/m-K)	5.75
MECHANICAL PROPERTIES	
Quasistatic properties at 23°C	
Unconfined strength (psi)	2450-3300
Secant modulus (psi)	2×10^6
Principal strain (Poisson's) ratio	0.25-0.35
Strain at failure (%) for confining pressure σ_3 of	
0 psi	2.5-6.0
500 psi	17-20
3000	20
Tensile strength (psi)	220
Initial yield stress ($\sigma_1 - \sigma_3$)(psi)	100
Preliminary creep properties	
Steady-state creep rate $\dot{\epsilon}$ (sec^{-1}):	
At 23°C and $\sigma_1 - \sigma_3$ = 1000 psi	10^{-10}
At 130°C and $\sigma_1 - \sigma_3$ = 2000 psi	10^{-7}

[a]Data from Powers et al. (1978, pp. 1-34ff).

7.2.5 Structure and Tectonics

Rock structures record past rock deformations. This record allows the reconstruction of the tectonic history (large-scale events involving the earth's crust) of the site and region and the evaluation of its general stability. This section summarizes tectonic and nontectonic mechanisms, deep structures, salt deformation, shallow structures, and man-made subsidence structures. More detailed descriptions are given elsewhere (Powers et al., 1978).

Tectonic and nontectonic mechanisms at the site

In the development of the Delaware basin preexisting rocks were deformed by the weight of rapidly deposited sediments and by tectonic stress from within the crust. The presence of thick salt beds strongly affects the deformations. Thick salt deforms plastically, very differently from the deformation of brittle rock. As a result, when tectonic forces act on a structure having a thick salt bed sandwiched between two layers of brittle rock, there need be no similarity between the deformations of the upper and the lower rock layers.

Differences in deformation above and below a salt layer also result from the collapse and deformation of rock units overlying active dissolution of a salt layer by unsaturated groundwater.

Clearly, then, structural features in the rocks that occur in the area are related to the position of these rocks in the geologic column. Accordingly, the following description of geologic structure at the site is organized into separate discussions of structures below the salt, the salt beds, and structures above the salt; also discussed is subsidence in the Potash Mining District close to the site to the west (Powers et al., 1978, pp. 4-54ff).

Deep structures

The Mid- and Early-Permian rocks beneath the salt beds slope east-southeast at about 50 feet per mile. The Paleozoic rocks beneath the Permian slope in the same direction but more steeply, at about 100 to 150 feet per mile. The nearest substantial fault is a north-trending fault about 15 to 20 miles east and southeast of the site, described by Foster (1974) and referred to as the "Bell Lake fault." It has a length of about 15 miles and a displacement of about 500 feet. Foster's work indicates that Upper Permian strata are not offset by the fault, but the deeper Permian strata are distorted near the fault (Powers et al., 1978, pp. 4-56ff).

Contour maps based on seismic reflection data of the Paleozoic strata below the salt show small faults running generally north-northeast and small, shallow domes and saddles several miles apart and several hundred feet from crest to trough.

Figures 7-10 and 7-11 (Griswold, 1977) show southwest-northeast and northwest-southeast sections, respectively, across the site. Faults arising in the basement rocks cut through the Pennsylvanian strata and fade out in the Permian. Faults indicated in the lower portion of the Castile are believed to be depositional-growth faults. They are not found in the Delaware Mountain Group. There is much less warping in the Delaware Mountain Group, and it is

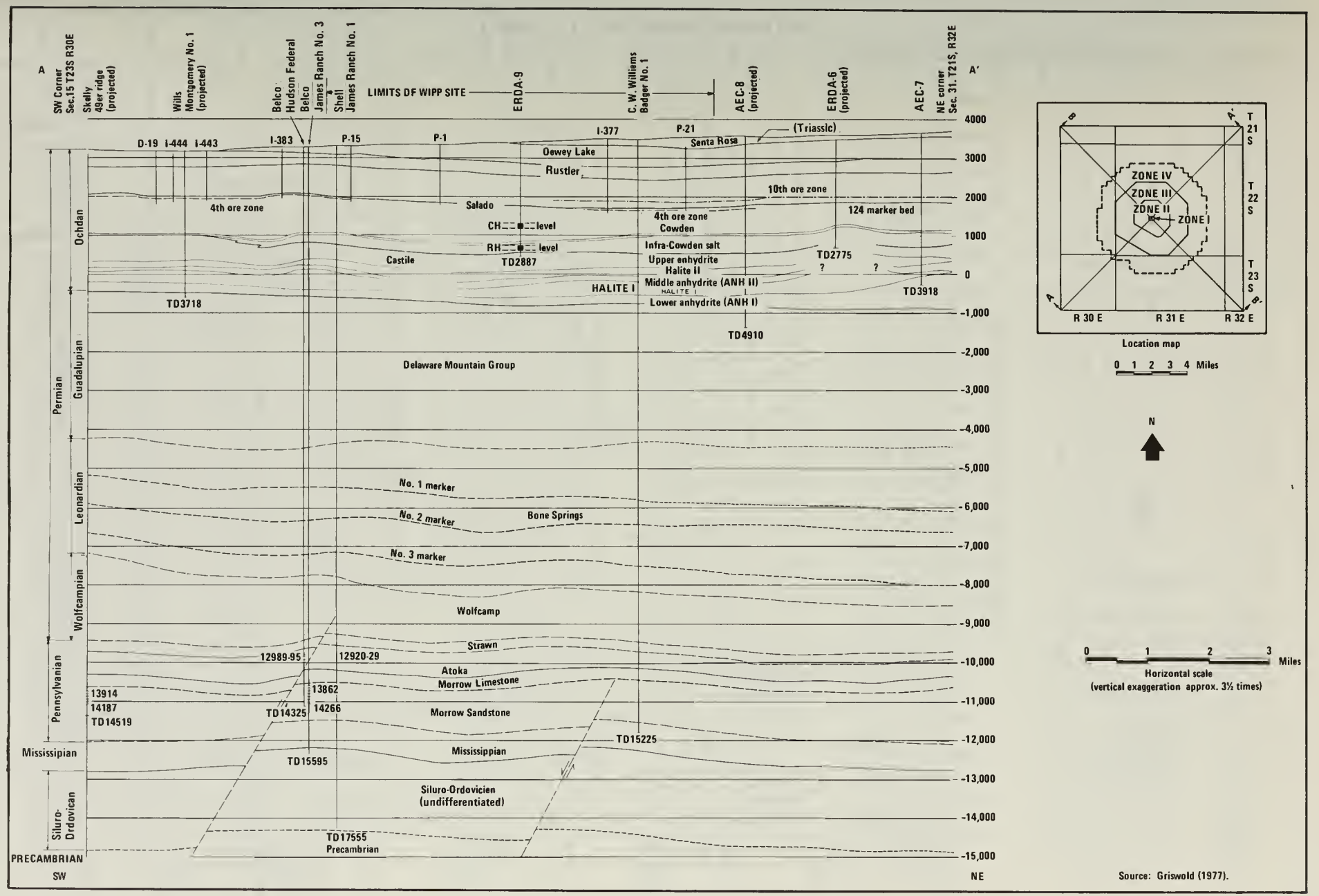

Figure 7-10. Site geologic section A-A'.

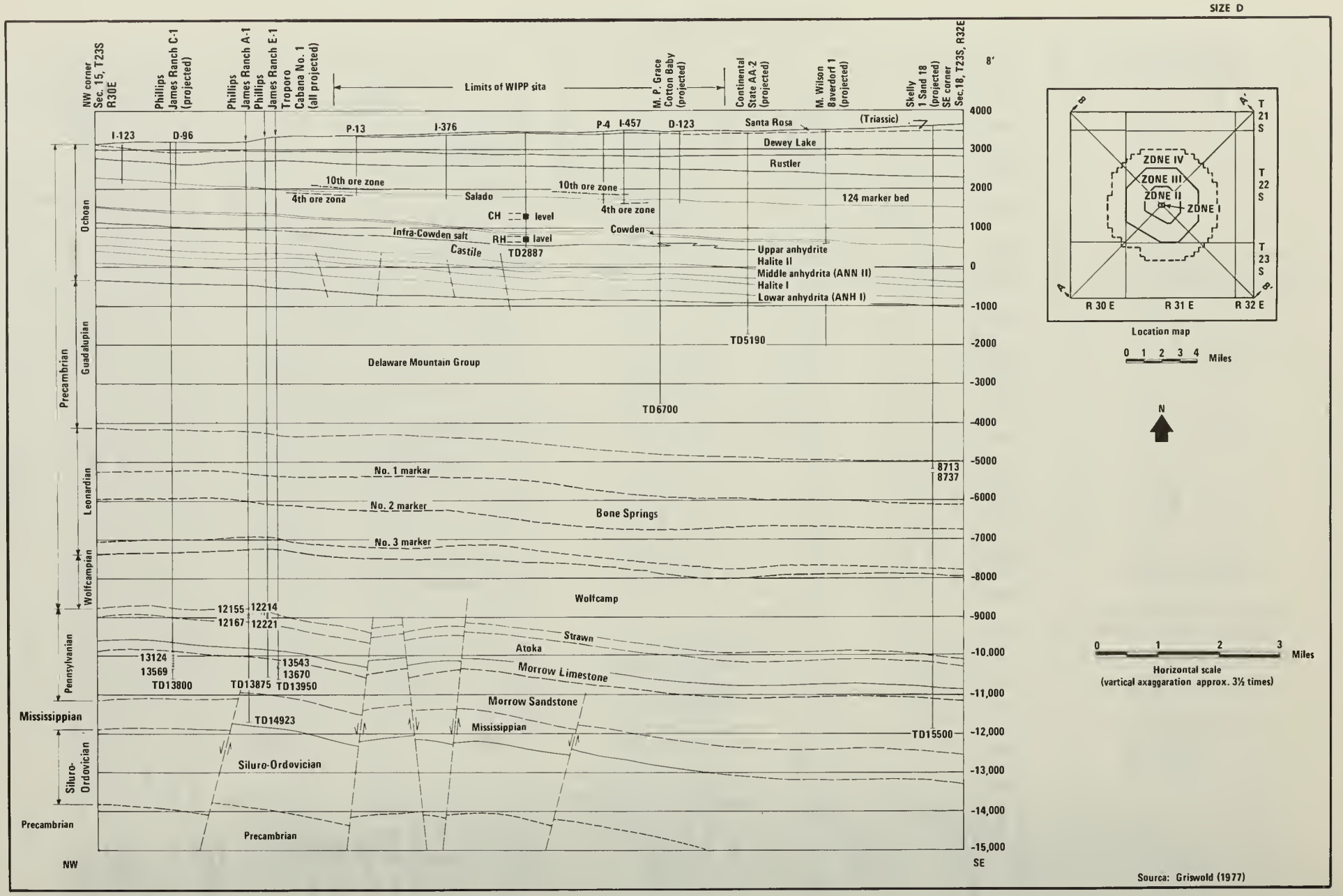

Figure 7-11. Site geologic section B-B′.

apparently unrelated to the deeper trends. The Delaware Mountain Group locally forms a northwest-trending saddle, with about 100 feet of structural relief, near the center of the site.

Structural differences between Delaware and pre-Permian strata suggest different origins and two periods of faulting. Below the Pennsylvanian all strata are deformed together, the intensity increasing with depth. Tectonic deformation apparently occurred in Late Pennsylvanian or Early Permian time and established the local structure of all pre-Permian rocks. Faults arising in the basement rocks cut into, but not through, the Pennsylvanian strata (Powers et al., 1978, pp. 4-59).

Salt deformation in the Castile and Salado Formations

In the northern Delaware basin, a structural feature common to all levels of the evaporite section is the uniformity in direction and slope of the gentle, even, southeastward dip (Figure 7-11) (Jones, 1973). Superimposed on the even dip are localized salt-flow structures; some may be Permian in age, others appear related to Delaware basin tilting of mid-Tertiary age (Powers et al., 1978, pp. 4-60ff).

The greatest deformation in the evaporite sequence at or near the site seems to be spatially related to a structural trough trending northwest-southeast and parallel to the base of the Capitan reef front about 8 miles north of the site. This trough is about 3 to 4 miles wide. Halite and anhydrite in the middle member of the Castile are folded, decreasing to the northwest and increasing to the southeast. This has caused buckling, down-warping, and uplift of the Salado in a broad arc trending northwestward across the area.

The belt of deformation sometimes includes salt-flow structures from the Castile (Anderson, 1978; Anderson and Powers, 1978). Some seem to have been formed when regional tilting caused plastic flow of salt against the Capitan reef. The time of the regional tilting has not yet been found, but it occurred after Late Triassic time and before uppermost Miocene time. Other salt structures do not appear to involve overlying Permian and post-Permian rocks, implying that in those instances deformation occurred at about the same time as deposition (Powers et al., 1978, pp. 4-61ff).

A ridge-and-saddle configuration trending northwest, with a crest-to-trough separation of 2 to 3 miles and a total structural relief of up to 400 feet is indicated by the contours of the top surface of the Castile Formation. Its origin is not known; it may be a depositional structure, or it may reflect past deformation by salt in underlying units.

Northeast of the site is a domelike structure with a core of mobilized Castile salt within the belt of salt deformation flanking the Capitan reef. A similar domelike structure without salt is southwest of the site.

The Salado has no traces of a northwest-southeast ridge such as the one suggested for the Castile. The two domelike structures are also present in the Salado, but there seem to be no such structures within the site.

Anderson (1978) has attributed some localized depressions within the evaporite units to "deep dissolution." In the central part of the basin to the south of the site, these "deep-seated sinks" may not show at the surface

and are not clearly related to the shallower dissolution features described below. These midbasin "deep sinks" may not be of recent origin. If they are, they may well be related to other collapse features in the Delaware basin region as different stages of a general process of erosion (Anderson, 1978, pp. 58-59).

Two depressions in the Salado occur near the site. One, identified by Anderson (1978, Figure 7) as a possible "deep sink," is nearly 4 miles east-southeast of the edge of control zone II. A second is centered about a mile north of zone II. This feature appears not to be a sink or breccia pipe, as other horizons are not affected and there is no resistivity anomaly. For site structures see the Geological Characterization Report (Powers et al., 1978).

In summary, the Salado Formation has a relatively uniform easterly dip of about 80 to 100 feet per mile across the site, and there is little evidence of any significant structural anomalies. No plastic deformation or buckling associated with salt flow seems to have occurred in the Salado as it has in the lower levels of the Castile. The artesian brine reservoirs sometimes found are associated with thickened salt sections and salt-flow structures in the Castile. No such deformation is recognizable within the site in any of the Salado strata; in fact, the site appears to be in a slight saddle.

Shallow structures

Rocks above the Salado Formation have been weathered and sometimes have secondary structures resulting from surficial dissolution and subsidence. Shallow structures at the site therefore have greater irregularity and complexity than do deeper rocks. "Shallow" is here defined to include all depths down through the Rustler Formation, or to a depth of about 850 feet beneath the center of the site (Powers et al., 1978, pp. 4-73ff).

The Rustler Formation in the southwestern part of the site has a dip of about 80 feet per mile to the southeast. Eastward thickening of the Rustler is related to the increasing amount of halite preserved. Subsurface data show that dissolution of 100 to 200 feet of salt has modified the surface and shallow subsurface structure but has not been accompanied by highly irregular subsidence structures in the overlying strata at the site.

The top of the Dewey Lake Red Beds does not slope eastward as do all lower Delaware basin horizons but slopes generally northeastward (Jones, 1973).

The surface sand at the site makes it hard to observe the surface geologic structure. In nearby Nash Draw the original structures are masked by the widespread slumping from salt dissolution. This surface jumbling is in Nash Draw and not between Livingston Ridge and the site.

No surface faults have been mapped within 5 miles of the center of the site. The faults that have been mapped are distant and are plainly related to collapse features.

Kelley (1971) suggests two faults that he calls the Barrer and Carlsbad faults at the foot of the Guadalupe Mountains west of the Pecos River. Others (e.g., Hayes, 1964, personal communication cited by Kelley) do not believe a fault is present. These are the nearest suspected recent faults, and they are still being investigated.

Livingston Ridge, 4 miles northwest of the site, marks the edge of Nash Draw. The rocks exposed here are strongly jointed, cavernous, and locally brecciated; stratification is generally obliterated (Jones, 1973). The process of dissolution is described in Section 7.3.

On the basis of aerial photographs and limited field work, Griswold (1977) suggested a fault on the west edge of Livingston Ridge. Since then, reexamination in the field has led him to change his mind (personal communication, February 20, 1978).

Man-made subsidence features

In the Carlsbad mining district (BLM, 1975) there has been subsidence during and after underground mining. Areas where subsidence effects have occurred (14 square miles) or are expected (40 square miles) are shown in Figure 7-12. These areas are north, northwest, and west of the site at distances from 3.5 to 26 miles. The maximum subsidence observed is about two-thirds of the height of the ore zone mined. Current ore zones are 4 to 8 feet thick; thus maximum subsidences are 2 feet 8 inches to 5 feet 4 inches.

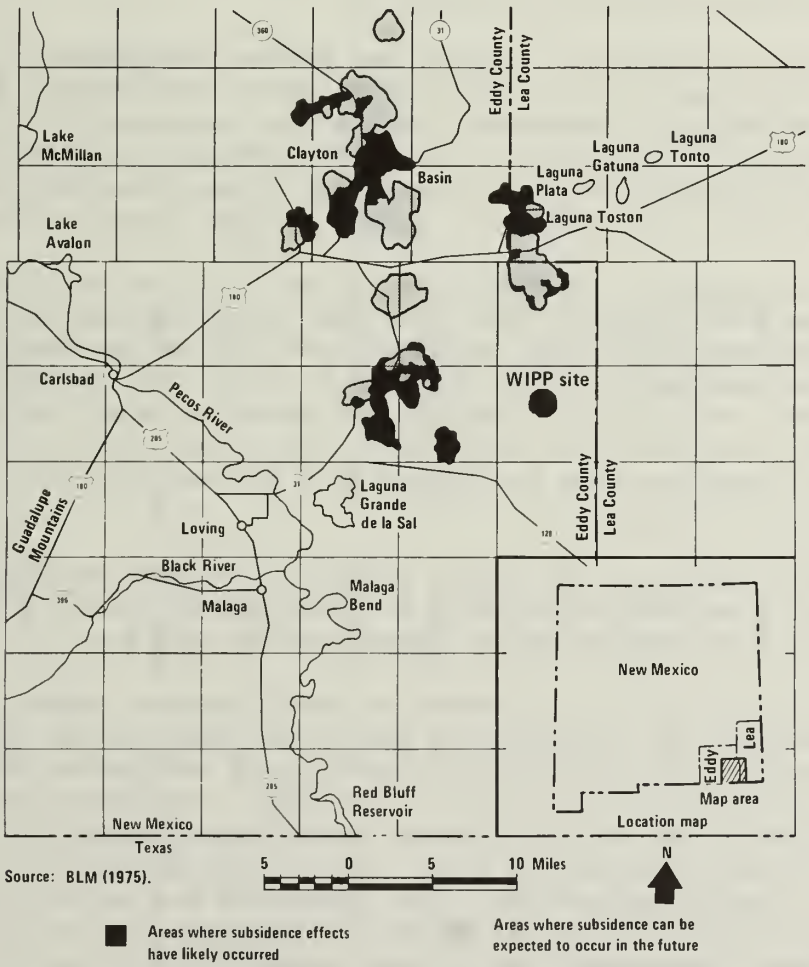

Figure 7-12. Generalized map of the Carlsbad mining district showing likely subsidence areas and expected future subsidence areas.

7.2.6 Seismology

The purpose of the seismic studies at the site is to build a basis from which to predict the ground motions that the WIPP facilities might be subjected to.

In this discussion all intensities are based on the Modified Mercalli Intensity Scale (Wood and Neumann, 1931). A detailed discussion of how magnitudes were determined for the various data sources is presented in the Geological Characterization Report (Powers et al., 1978, pp. 5-10ff).

Seismic history

Regional seismicity is presented here in two time frames, before and after the time when seismograph data became available.

Sanford and Toppozada (1974) have examined various records to determine the seismic history within 180 miles of the site. Their results for the period before 1962 are given in Table 7-3. With the exception of the weak shock in 1926 at Hope, New Mexico, and the shocks in 1936 and 1949 felt at Carlsbad, all known shocks before 1962 occurred to the west and southwest of the site and more than 100 miles away.

Since 1962 instrumental coverage has become comprehensive enough to locate most of the moderately strong earthquakes (local magnitude $\geq$ 3.5) in the region. Instrumentally determined shocks that occurred within 180 miles of the site since 1962 are listed in Table 7-4 and shown in Figure 7-13. Their distribution may be biased by the fact that seismic stations were more numerous and were in operation for longer periods north and west of the site.

Except for the activity southeast of the site, the distribution of epicenters since 1962 differs little from that of shocks before that time. There is clustering associated with the Rio Grande Rift on the Texas-Chihuahua border and on the Central Basin platform in Texas near the southeastern corner of New Mexico. Surprisingly, "earthquake activity is as intense in the stable physiographic provinces, the High Plains and the Colorado Plateau, as it is in the unstable provinces, the Rio Grande Rift and southern Basin and Range" (Sanford et al., 1978).

It is not clear from the record whether there were earthquakes in the Central Basin platform before 1965, although local historical societies and newspapers tend to confirm their absence before that time.

A station operated for 10 months at Fort Stockton, Texas, indicated many small shocks from the Central Basin platform. Activity was under way when the station opened on June 21, 1964. Shurbet (1969) suggested that this activity is related to water injection for oil recovery. The known hydrocarbon resources nearest the site are two gas wells approximately 3 miles to the southwest of the center of the site. The nearest oil fields in the Delaware basin are 7 miles from the site. The suggestion has merit in that the Central Basin platform is an old structure (Early Permian), with no surface indication of having been rejuvenated, and in that enormous quantities of water have been injected. In one of the oil fields, the Ward-Estes North operated by the Gulf Oil Corporation, the cumulative total of water injected up to 1970 was over 1 billion barrels. It accounted for 42% of the water injected in Ward and

Table 7-3. Reports of Felt Earthquakes Within 180 Miles of the WIPP Reference Site Before 196]

Date	Time (GMT)	Location of maximum reported intensity	Distance (km) and direction from site	Maximum reported intensity[a]	References[b]	Remarks
1923 Mar 7	04:03	El Paso, Tex.	260, S75W	V	1-3	Felt in Sierra Blanca (166 km to SE). Columbus (130 km to W), Alamogordo (135 km to N). Newspaper accounts suggest epicenter in northern Chihuahua.
1926 July 17	22:00	Hope and Lake Arthur, N.M.	90, N54W	III	4	Earth sounds heard in NE direction at Hope; windows rattled at Lake Arthur.
1930 Oct 4	03:25	Duran, N.M.	280, N32W	(IV)	5	Moderate shock felt by many. Rolling motion, rumbling sound, rattled windows. No damage.
1931 Aug 16	11:40	Valentine, Tex.	210, S20W	VIII	5-7	Strong damaging earthquake. Felt over 1,250,000 $km.^2$ See text.
1931 Aug 16	19:33	Valentine, Tex.	210, S20W	(V)	5	Strong aftershock.
1931 Aug 18	19:36	Valentine, Tex.	210, S20W	V	5	Strong aftershock.
1931 Aug 19	01:36	Valentine, Tex.	210, S20W	(V)	5	Strong aftershock.
1931 Oct 2	?	El Paso, Tex.	260, S75W	(III)	5	Feeble shock.
1931 Nov 3	14:50	Valentine, Tex.	210, S20W	(V)	5	Strong aftershock of Aug. 16, 1931 earthquake.
1935 Dec 20	05:30	Clovis, N.M.	230, N13E	III-IV	8	Two shocks. Tile wall in creamery cracked.
1936 Jan 8	06:46	Carlsbad, N.M.	40, N89W	(IV)	3,5	Newspaper account indicates this event was probably centered near Ruidoso, N.M.
1936 Aug 8	01:40	El Paso, Tex.	260, S75W	(III)	3,5	Weak shock not felt elsewhere.

Table 7-3. Report of Felt Earthquakes Within 180 Miles of the WIPP Reference Site Before 1961 (continued)

Date	Time (GMT)	Location of maximum reported intensity	Distance (km) and direction from site	Maximum reported intensity[a]	References[b]	Remarks
1936 Oct 15	18:	El Paso, Tex.	260, S75W	(III)	5	Slight shock.
1937 Mar 31	22:45	El Paso, Tex.	260, S75W	(IV)	3,5	Felt by many.
1937 Sept 30	06:15	Ft. Stanton, N.M.	200, N53W	(V)	5	Awakened many.
1943 Dec 27	04:00	Tularosa, N.M.	220, N70W	IV	9	Rattled windows.
1949 Feb 2	23:00	Carlsbad, N.M.	40, N89W	(IV)	5,9	Two distinct shocks felt by several, and a few frightened. Windows, doors, dishes rattled.
1949 May 23	07:22	East Vaughn, N.M.	280, N28W	VI	5,9	Felt area 33-km strip connecting East Vaughn and Pastura. At East Vaughn few things fell from shelves, loose objects rattled
1952 May 22	04:20	Dog Canyon, N.M.	158, N79W	IV	5,9	Felt by two in ranch house. Windows, doors, dishes rattled.
1955 Jan 27	00:37	Valentine, Tex.	210, S20W	IV	5,9	Felt by many. Houses shaken.

[a]Based on the Modified Mercalli Intensity Scale of 1931. Intensities given in parentheses were assigned by the authors.

[b]The numbers in this column are for the references listed below.

1. Woollard (1968).
2. Bull. Seismol. Soc. Amer. (1923).
3. Newspaper account.
4. S. A. Northrop, personal communication.
5. U.S. Earthquakes (NOAA and USGS, published annually).
6. Sellards (1933).
7. Byerly (1934).
8. Northrop and Sanford (1972).
9. Abstracts of Earthquake Reports for the Pacific Coast and Western Mountain Region (NOAA).

Table 7-4. Instrumentally Located Earthquakes That Have Occurred Within 180 Miles of the Site Since 1961[a]

Date (yr/mo/day)	Origin time	Location		Magnitude[b]	
		Lat. N	Long. W	M (NMT)	M (USGS)
62/3/3	18:16:47	33.8	106.4	1.2	
62/3/6	09:59:10	31.1	104.6	3.0	
64/2/11	09:24:10	34.4	103.7	2.5	
64/3/3	01:26:27	35.0	103.6	2.2	
64/6/18	20:20:18	33.1	106.1	1.2	
64/6/19	05:28:39	33.1	106.0	1.7	
64/11/8	09:26:00	31.9	103.0	2.7	3.0
64/11/21	11:21:24	31.9	103.0	2.5	3.3
65/2/3	19:59:32	31.9	103.0	3.0	3.9
65/4/13	09:35:46	30.3	105.0	2.5	
65/8/30	05:17:30	31.9	103.0	2.6	3.3
66/8/14	15:25:47	31.9	103.0	2.8	4.1
66/8/17	18:47:21	30.7	105.5	2.9	
66/8/19	04:15:44	30.3	105.6	4.6	
66/8/19	08:38:21	30.3	105.6	3.6	
66/9/17	21:30:13	34.9	103.7	2.2	
66/11/26	20:05:41	30.9	105.4	2.6	
66/11/28	02:20:57	30.4	105.4	3.3	
66/12/5	10:10:37	30.4	105.4	3.3	
67/9/29	03:52:41	32.3	106.9	2.0	
68/3/9	21:54:26	32.7	106.0	2.9	
68/3/23	11:53:39	32.7	106.0	2.3	
68/5/2	02:56:44	33.0	105.3	2.6	
68/8/22	02:22:26	34.3	105.8	2.1	
69/5/12	08:26:18	32.0	106.4	3.0	
69/5/12	08:49:16	32.0	106.4	2.6	
69/6/1	17:18:24	34.2	105.2	2.0	
69/6/8	11:36:02	34.2	105.2	2.4	
69/10/19	11:51:34	30.8	105.7	2.8	
71/7/30	01:45:50	31.7	103.1	3.1	4.5
71/7/31	14:53:48	31.6	103.1	3.2	4.2
71/9/24	01:01:54	31.6	103.2	3.0	3.8
72/2/27	15:50:04	32.9	106.0	2.3	
72/7/26	04:35:44	32.6	104.1	2.8	
72/12/9	05:58:39	31.7	106.4	2.2	
72/12/10	14:37:50	31.7	106.5	2.2	
72/12/10	14:58:02	31.7	106.5	1.8	
74/8/17[c]	07:35:18	30.4	105.8	3.5	
74/8/26	07:33:22	34.4	105.8	2.4	
74/9/26	23:44:09	32.9	106.2	2.4	1.7
74/10/15	10:07:58	33.9	106.5	2.3	
74/11/01	10:45:50	33.8	106.6	2.0	
74/11/12	02:31:57	31.9	100.8	2.5	2.4
74/11/12	07:14:29	31.9	100.8	2.2	2.2
74/11/21	16:22:59	32.5	106.3	2.4	
74/11/21	18:59:06	32.1	102.7	2.1	2.7
74/11/22	08:54:05	32.8	101.5	2.0	2.1
74/11/22	14:11:13	33.8	105.1	1.9	
74/11/28	03:35:21	32.6	104.1	3.6	3.9

Table 7-4. Instrumentally Located Earthquakes That Have Occurred Within 180 Miles of the Site Since 1961[a] (continued)

Date (yr/mo/day)	Origin time	Location		Magnitude[b]	
		Lat. N	Long. W	M (NMT)	M (USGS)
75/02/02	20:39:23	35.1	103.1	2.7	
75/07/25	08:11:40	29.9	102.5	2.8	
75/08/01	07:27:47	30.4	104.6	3.9	2.8
75/10/10	11:16:56	33.3	105.0	2.1	2.0
76/01/10	01:49:57	31.7	102.8	2.1	
76/01/19	04:03:30	31.9	103.0	2.4	3.5
76/01/22	07:21:58	31.9	103.0	2.0	2.8
76/01/25	04:48:28	32.0	103.1	2.9	3.9
76/01/28	07:37:49	32.0	101.0	2.4	3.4
76/03/18	23:07:05	32.2	102.9	1.6	
76/3/20[c]	12:42:20	31.2	105.0	2.3	
76/3/20	16:15:58	32.2	103.1	1.4	1.7
76/3/27	22:25:22	32.2	103.1	1.8	1.5
76/4/1[c]	14:40:26	34.1	105.8	2.8	
76/4/1	14:46:58	33.9	106.0	2.6	
76/4/1	14:51:17	33.9	105.9	2.8	
76/4/6	18:09:00	33.9	105.0	2.7	
76/4/18	03:48:19	33.9	106.0	2.1	
76/4/21	08:40:06	32.3	102.9	1.7	2.5
76/5/3	06:52:59	32.4	105.6	2.4	
76/5/4[c]	15:05:40	32.0	103.2	1.9	2.3
76/5/6	17:18:24	32.0	103.2	1.8	2.6
76/5/8[c]	11:46:38	32.0	102.8	1.8	1.9
76/5/11[c]	23:04:38	32.3	102.8	1.9	
76/5/21	13:17:35	32.3	105.3	2.2	
76/5/26[c]	11:52:26	32.4	102.6	1.7	
76/6/14[c]	23:29:50	31.6	101.9	2.3	
76/6/15	02:19:58	31.6	102.4	1.7	2.4
76/6/15	08:50:20	31.5	102.4	2.1	2.7
76/6/16[c]	14:05:12	31.6	101.9	2.3	
76/8/5[c]	22:23:29	30.8	101.8	3.0	
76/8/10	09:03:12	31.8	102.2	1.4	2.4
76/8/10	10:15:14	31.8	102.2	1.7	2.9
76/8/25[c]	01:21:01	32.8	101.1	2.8	
76/8/25	01:27:49	31.5	102.5	1.8	2.8
76/8/26	15:22:13	31.8	102.2	1.7	3.0
76/8/30	11:51:25	31.5	102.6	1.4	
76/8/30	13:07:48	33.9	106.3	2.3	
76/8/31	12:46:22	31.5	102.8	1.9	2.8
76/9/5	10:39:46	32.2	102.8	1.4	1.7
76/9/10[c]	23:17:48	30.9	101.7	2.8	
76/9/17	02:47:47	32.2	103.1	2.1	3.0
76/9/19	10:40:46	30.6	104.5	3.0	
76/10/13[c]	19:11:06	32.0	103.0	1.5	
76/10/14	11:02:60	32.3	103.1	0.9	
76/10/22	05:06:12	31.5	102.2	2.0	2.9
76/10/23	12:51:37	31.6	102.4	1.6	
76/11/3	23:24:15	31.0	102.5	1.8	
77/1/4	18:03:38	32.4	106.9		3.2

Table 7-4. Instrumentally Located Earthquakes That Have Occurred Within 180 Miles of the Site Since 1961[a] (concluded)

Date (yr/mo/day)	Origin time	Location		Magnitude[b]	
		Lat. N	Long. W	M (NMT)	M (USGS)
77/1/29	09:40:44	30.6	104.6	2.1	
77/02/10	01:22:49	32.3	103.1	1.0	2.0
77/3/14[c]	10:10:22	32.9	100.8	3.5	
77/3/19[c]	21:27:49	31.3	102.8	2.2	
77/3/20[c]	07:54:05	32.3	102.8	2.3	2.2
77/4/12[c]	23:18:27	31.2	102.6	2.9	2.2
77/4/16[c]	06:44:22	31.2	102.9	2.1	1.3
77/4/17[c]	21:47:07	31.5	102.0	2.1	
77/4/26[c]	09:03:05	31.9	103.0	2.6	3.1
77/6/7[c]	23:01:17	32.7	100.6	4.5	
77/6/8[c]	00:51:29	32.8	100.8	4.0	
77/6/17[c]	03:37:05	32.8	100.9	3.9	
77/8/3[c]	02:11:48	32.8	105.3	2.5	
77/8/21[c]	03:01:16	30.8	104.8	3.4	
77/11/28	01:40:51	33.0	100.8		3.5

[a]Data from Sanford and Toppozada (1974), Sanford et al. (1978), Rogers and Malkiel (1978), and Preliminary Determination of Epicenters (USGS).

[b]The frequent difference of about one magnitude unit between local magnitudes estimated by Sanford et al. (1978) and by the USGS (Rogers and Malkiel, 1978) comes from a New Mexico distance correction used by Sanford et al. (1978, p. 27), but not by the USGS.

[c]Tentative epicenters.

Winkler Counties, Texas, and the quantity is three times the total injected in all the oil fields of southeastern New Mexico in the same period.

The strongest earthquake on record within 180 miles of the site was the Valentine, Texas, earthquake of August 16, 1931 (event 4 in Table 7-3). Coffman and von Hake (1973) estimate it to have been of magnitude 6.4 (MM Intensity VIII). The Valentine earthquake was 130 miles south-southwest of the site. Its MM intensity at the site is estimated at V; this is believed to be the highest intensity felt at the site in this century.

In 1887, a major earthquake occurred in northeast Sonora, Mexico. Although about 335 miles west-southwest of the site, it is indicative of the size of earthquakes possible in the eastern portion of the Basin and Range province, west of the province containing the site. Sanford and Toppozada (1974) estimate its magnitude to have been 7.8, and Coffman and von Hake (1973) list it as VIII-IX in MM intensity. It was felt over an area of 0.5 million square miles (as far as Santa Fe to the north and Mexico City to the south); fault displacements were as large as 26 feet, and Bavispe, Mexico, was reduced to ruins (Aguilera, 1920).

Local observations

From April 1974 to October 1977, 291 events identifiable as local and regional earthquakes were recorded by a station (CLN) 4 miles from the center

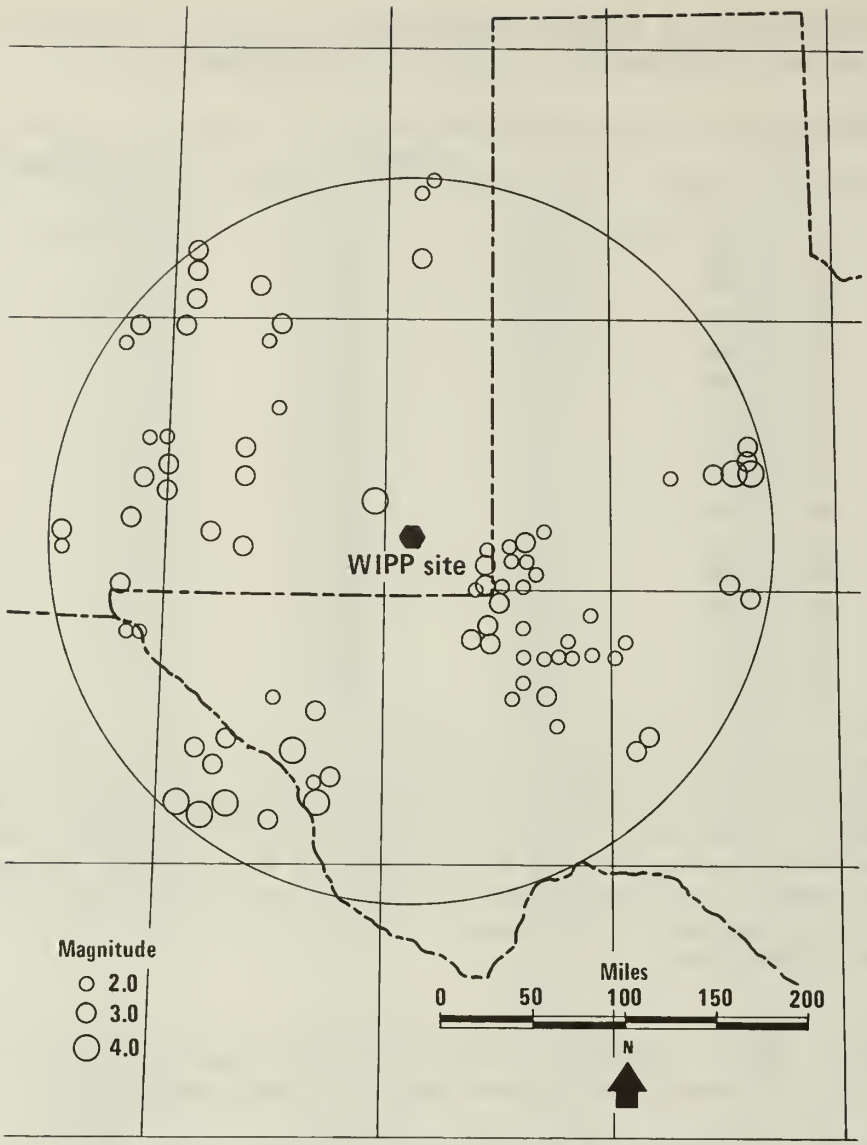

Figure 7-13. Regional earthquake epicenters.

of the site (see Appendix J). For seventy-five of the 291 events the epicenters were identified. These seismic patterns are similar to those of the instrumental data.

Local earthquakes. Tectonism and seismic activity near or at the site are of great interest. Two of the most important seismic events instrumentally recorded are the two close to the site: the events of July 26, 1972, and November 28, 1974. They had magnitudes of 2.8 and 3.6, respectively, and both were about 25 miles to the northwest. At both times rockfalls and ground cracking were reported at an active potash mine. To determine whether collapse at this mine was responsible for both events, an analysis was made of whether the two epicenters coincided. They were about 6 miles apart. Thus the two events cannot have been caused by the mine. Moreover, the earthquake had too much energy to have been caused by the rockfall. Lacking additional seismic data on these events, seismic risk at the site should be estimated on the assumption that both were natural (Caravella and Sanford, 1977).

Another event occurred about 10 miles northeast of station CLN on January 19, 1978. Unlike the previous two, it did not happen at the same time as any known mine activity. Three other earthquakes have been recorded within 35 miles of station CLN, but because they were recorded only by that station, their epicenters cannot be obtained, and they were probably minor.

Seismic risk

Maps of the position and intensity of recorded earthquakes are useful in evaluating the probability of an earthquake at a given site. To increase their usefulness, the historical data have been supplemented with field geologic data.

Several researchers have divided the United States into zones of earthquake risk. The standard estimate is that of Algermissen (1969). According to this estimate, the site is located in seismic risk zone 1, where only minor damage is to be expected, corresponding to Modified Mercalli Intensity V to VI. Earlier, Richter (1959) had placed the region within a seismic zone where the probable maximum intensity would be VIII. Sanford and Toppozada (1974) thought the site to be either on the boundary of zones 2 and 3 or within zone 2, depending on whether earthquakes in the Central Basin platform are found to be natural or man-made.

One desires not only an estimate of the largest seismic motions possible at a site but also an estimate of their probability. Such an estimate has been made for the WIPP reference site, starting with analysis of seismic recurrence rates of nearby active areas.

Earthquakes in the Central Basin platform. The Central Basin platform is a structural feature less than 30 miles east of the site, adjacent to the Delaware basin. Instrumental studies have shown the Central Basin platform to be much more active than would be expected from its stable tectonic setting. Primarily for this reason the Kermit, Texas, seismographic station array was established in late 1975. During the period from November 1975 to July 1977, 407 local events were detected and 135 located with array data.

The Central Basin platform has been active since at least mid-1964. It has been the most active seismic area within 180 miles of the site in the number of events, but not in intensity. The data imply that seismic activity is equally likely to occur anywhere along the Central Basin platform, without any clear relationship to small-scale structural details such as pre-Permian buried faults. Attempts have been made to relate this seismicity to oil recovery, but such a relationship has not been unequivocally established.

In 1978, Sanford et al. (1978) had accumulated enough data to calculate the apparent recurrence rates for earthquakes on the Central Basin platform. The distribution of minor shocks implied a recurrence rate of every 10,000 years for earthquakes of the size of the 1887 Sonoran event. There is no evidence that such earthquakes have occurred (fault scarps 25 miles long would be expected from shallow quakes such as these, with displacements of perhaps 10 feet; they are not found). To explain this discrepancy three possible explanations have been advanced:

1. Crustal movement has only recently resumed on the Central Basin platform.

2. The structure of the Central Basin platform imposes a limit on the possible magnitude of earthquakes.

3. The minor shocks observed were caused by human activity.

For the analysis that follows we assume the second explanation, even though the evidence seems to support the third.

The method of Cornell (1968) was used to estimate seismic risk at the site (Powers et al., 1978, pp. 5-32ff). He used three source regions suggested by Algermissen and Perkins (1976): the Rio Grande rift, the Central Basin platform, and the remainder of the area within 180 miles of the reference site (site source zone). The analysis used Sanford's recurrence relationships (Sanford et al., 1976, 1978). On the basis of the earthquake of 1887, an upper limit of 7.5 was set on the magnitude of earthquakes in the Rio Grande rift.* On the basis of the largest earthquake observed so far (magnitude 3.2) and considering the uncertainties in source mechanisms, he set the upper limit magnitude for the Central Basin platform at 5 and 6 in separate calculations. The largest earthquake so far observed in the remaining region (the site source zone) was of magnitude 3.6; from this, and from the absence of any indication of Holocene local faulting, he set the upper limit in the site region at 4.5 and 5 in separate calculations. He assumed the depth of earthquakes in the site source zone to be 3 miles.

The Cornell method expresses seismic risk as the probability per year that a specific acceleration will be reached or exceeded. These probabilities, as evaluated for the reference site, are shown in Figure 7-14.

Figure 7-14 shows the separate contributions to these totals of each of the three source regions with each of the assumed upper magnitude limits. The contribution of the Rio Grande Rift source zone to the total seismic risk at the site is small at all acceleration levels. The A and B curves and the C and D curves indicate the total combined acceleration for the various combinations of upper magnitude limits indicated above.

From Figure 7-14 the accelerations that would be experienced at the site from earthquakes in the three source zones separately are as follows for two levels of probability:

Source zone	Upper limit magnitude	Acceleration g for probability (per year)	
		10^{-8}	10^{-6}
Rio Grande rift	7.5	0.14	0.09
Central Basin platform	6.0	0.17	0.15
Central Basin platform	5.0	0.07	0.07
Site source zone	5.0	0.3	0.23
Site source zone	4.5	0.21	0.17

*The fact that this magnitude is less than Sanford and Toppozada's (1974) estimate of 7.8 does not affect the conclusions of the analysis.

The total seismic risk is controlled by earthquake probabilities in one of these source zones, depending on the acceleration level considered. The relationships are shown below.

Upper limit magnitude			Controlling zone	
Rio Grande rift	Central Basin platform	Site source zone	High acceleration	Low acceleration
7.5	5	4.5	SSZ[a]	SSZ
7.5	6	4.5	SSZ	CBP[b]
7.5	5	5.0	SSZ	SSZ
7.5	6	5.0	SSZ	CBP

[a]Site source zone.
[b]Central Basin platform.

Thus assumptions about seismic properties of the area around and beneath the site (site source zone) are important in estimating seismic accelerations at the reference site.

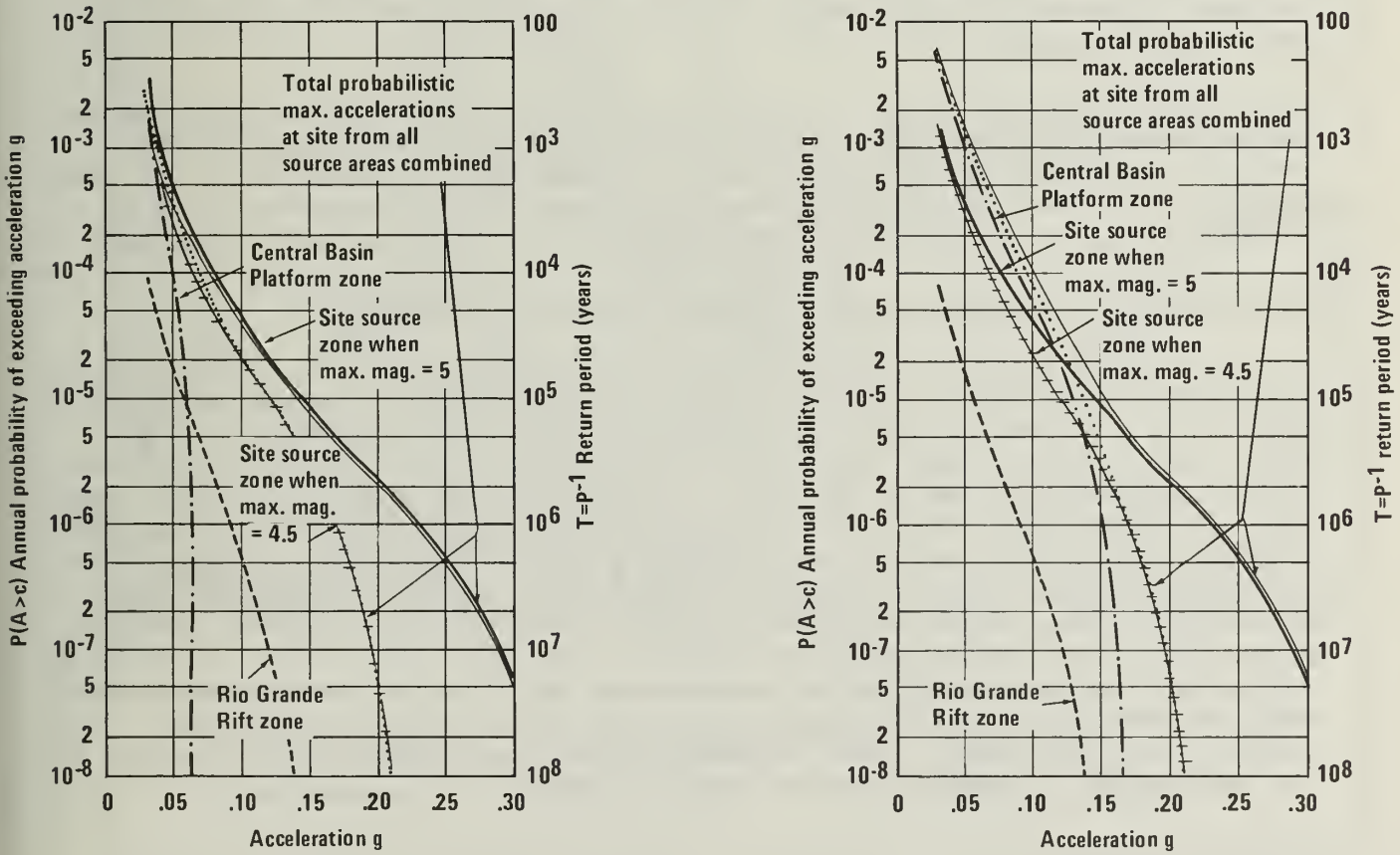

Figure 7-14. Seismic risk when the maximum magnitude event is assumed to be 6.0 (left) and 5.0 (right). The following maximum magnitudes are assumed for the site and the Central Basin platform source zones, respectively: curve A, 5 and 6; curve B, 4.5 and 6; curve C, 5 and 5; curve D, 4.5 and 5. Complete descriptions of the assumptions underlying these and the remaining curves may be found in the Geological Characterization Report (Powers, et al., 1978).

7.2.7 Energy and Mineral Resources*

Geologic studies related to site evaluation have included investigation of mineral resources so that an evaluation could be made of the impact of denying access to these resources. Of the mineral resources expected to occur beneath the site, only five are of concern: the potassium salts sylvite and langbeinite, which occur in strata above the repository salt horizons, and the hydrocarbons crude oil, natural gas, and distillate (liquids associated with natural gas), which occur in strata below the repository horizons. The other mineral resources beneath the site are caliche, salt, and gypsum; enormous deposits of these resources near the site and elsewhere in the country are more than adequate to meet future requirements for these materials (Powers et al., 1978, pp. 8-2ff).

The shape, thickness, depth, and grade of the potassium salts and hydrocarbons under the site had to be established first. These data formed the basis for calculating the total amount of resources. The next step was to determine to what extent these resources could be classified as reserves. The latter term is restricted to resources that can be extracted profitably with existing technology and under present economic conditions. Obviously resources will exceed reserves because reserves are a part of resources. It is logical to compare relative quantities of a mineral either on a basis of resources or of reserves; however, the comparison of resources at a site with reserves elsewhere (or vice versa) is to be guarded against (Powers et al., 1978, pp. 8-5ff).

A further caution is in order. Because the United States has high technological expertise in mineral exploration and extraction, estimates of U.S. resources and reserves are considered to be much more firm than those for some foreign countries. Foreign estimates can be too low because of the lack of exploration or too high if an incentive exists to attract outside investment.

Methods used to determine potash resources at the reference site

The site is adjacent to the Carlsbad Potash Mining District. This single district provides 80% of the U.S. domestic supply of potassic chemical fertilizers. Private companies have done potash exploratory drilling near the site. The results of that drilling were supplemented by 21 exploratory holes drilled in the site area by the DOE to evaluate potash deposits. In all, data were available from 61 holes drilled by industry, the 21 holes drilled by the DOE, and 2 site-characterization exploratory holes--a total of 84 holes. The locations of these holes are shown in Figure 7-15. While the spacing of the holes is variable, in no case are they more than 1 mile apart within the site boundaries. Five additional holes drilled by the Duval Corporation in early 1978 after the potash evaluation was made for the site are located immediately west and outside the site boundary (see locations of holes D-231, D-233, D-235, D-248, and D-250). The information from these holes does not affect the evaluation of potash resources under the site.

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*A more comprehensive description of the energy and mineral resources of the site is presented in the Geological Characterization Report (Powers et al., 1978, Chapter 8).

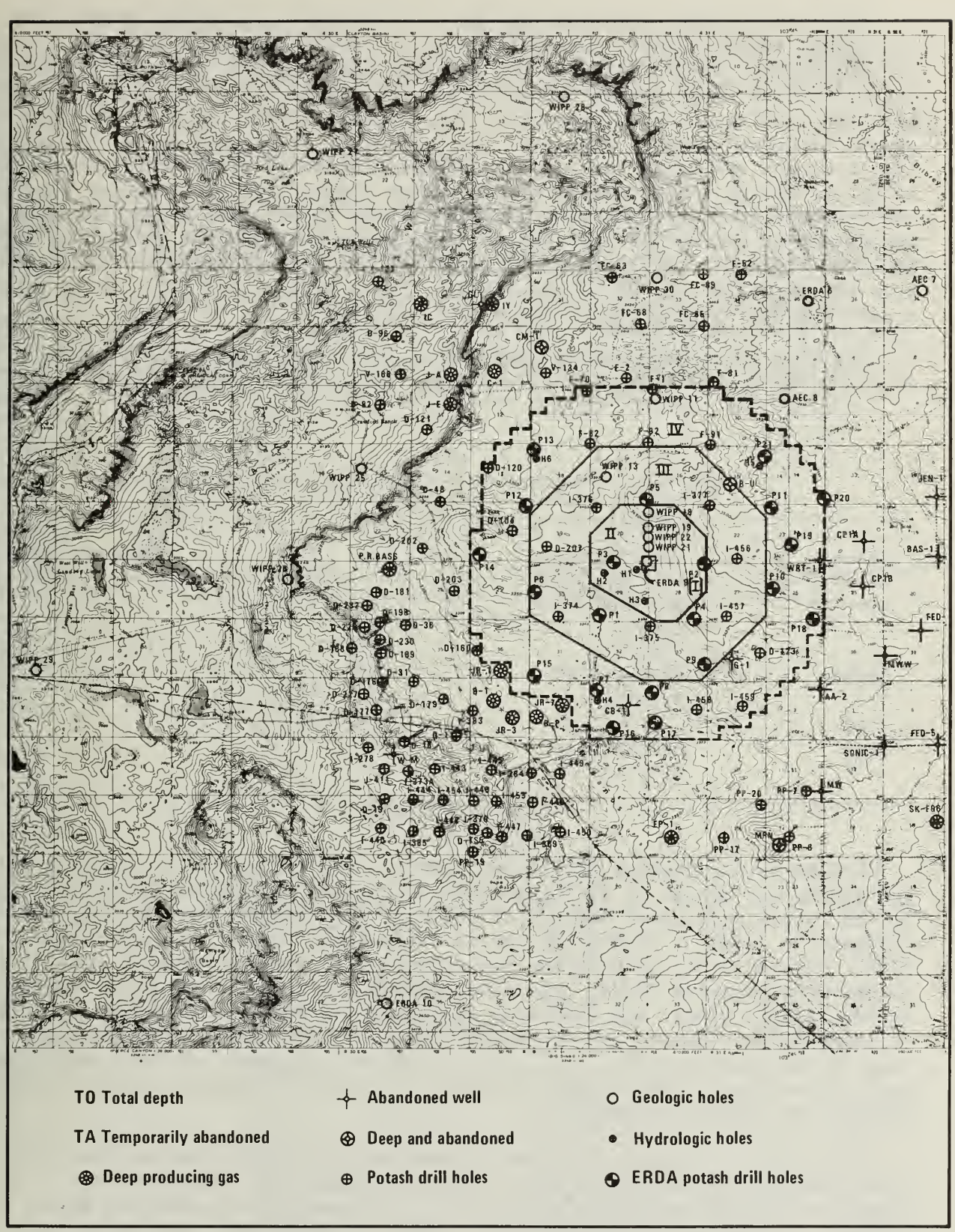


Figure 7-15. Location of all exploration drill holes within a square, 10 miles on a side, centered at the WIPP reference site. The figure also shows several exploration holes drilled by the ERDA and the DOE outside this square.

Evaluating potash resources at the site was the responsibility of the U.S. Geological Survey (USGS). Descriptive data, including sample analysis, of the 21 exploratory holes drilled by the DOE have been reported by Jones (1978). An estimate of total potash resources has been reported by John et al. (1978). The USGS used established procedures for determining the volume, thickness, and grade for bedded mineral deposits. The essential steps were to (a) determine the thickness and grade for each mineralized intercept discovered in each hole, (b) assign the mineralized zone to the appropriate ore bed, (c) determine the probable continuity of mineralized ore beds to adjacent holes, and then (d) determine the volume and average grade for a bed enclosed in plan by the smallest triangular array formed by adjacent and mineralized holes. Reasonable extrapolation was permitted outward from a mineralized hole toward barren areas, but the distance never exceeded 0.5 mile.

The USGS established three standard classes--low, lease, and high--to quantify the potash resources at the site. These are listed in Table 7-5.

Table 7-5. Standard Conditions for Potash Resources

Class	Type of ore	% K_2O	Thickness (ft)
Low	Langbeinite	3	4
	Sylvite	8	4
Lease	Langbeinite	4	4
	Sylvite	10	4
High	Langbeinite	8	4
	Sylvite	14	4

Potash salts, whether sylvite or langbeinite, are marketed according to the equivalent amount of K_2O present as determined by chemical analysis. It is the industry-accepted measure of quality, even though sylvite (KCl) and langbeinite ($K_2SO_4 \cdot 2MgSO_4$) do not in themselves contain oxide of potassium. Pure sylvite contains the equivalent of 63.17% K_2O, whereas pure langbeinite contains 22.7%. Raw ores contain a mixture of minerals, mostly halite (salt), clays, and insoluble evaporites in addition to either sylvite or langbeinite. Hence, raw ore always contains much less equivalent K_2O than do the pure minerals. All potash ores are upgraded into marketable products by refining. The accepted standard for refined products is 60% K_2O for sylvite and 22% for langbeinite.

At present, the average grades of ores being mined in the Carlsbad district are 14% K_2O as sylvite and 8% K_2O as langbeinite. Therefore the high standard set by USGS is equivalent to current mining costs and market prices. The median standard, termed "lease" in Table 7-5, represents the lowest grades of sylvite (10% K_2O) and langbeinite (4% K_2O) ores treated by Carlsbad refineries. The low standard, 8% K_2O as sylvite or 3% K_2O as langbeinite, represents a lower limit, presently uneconomic for mining at Carlsbad.

All three standard conditions are accompanied by a minimum thickness of 4 feet, the minimum seam thickness for efficient mining. If an ore bed is thinner than 4 feet, it must have an offsetting increase in K_2O content of potassium salts such that if diluted with barren material it still meets the established grade criteria.

Results of the potash-resource evaluation

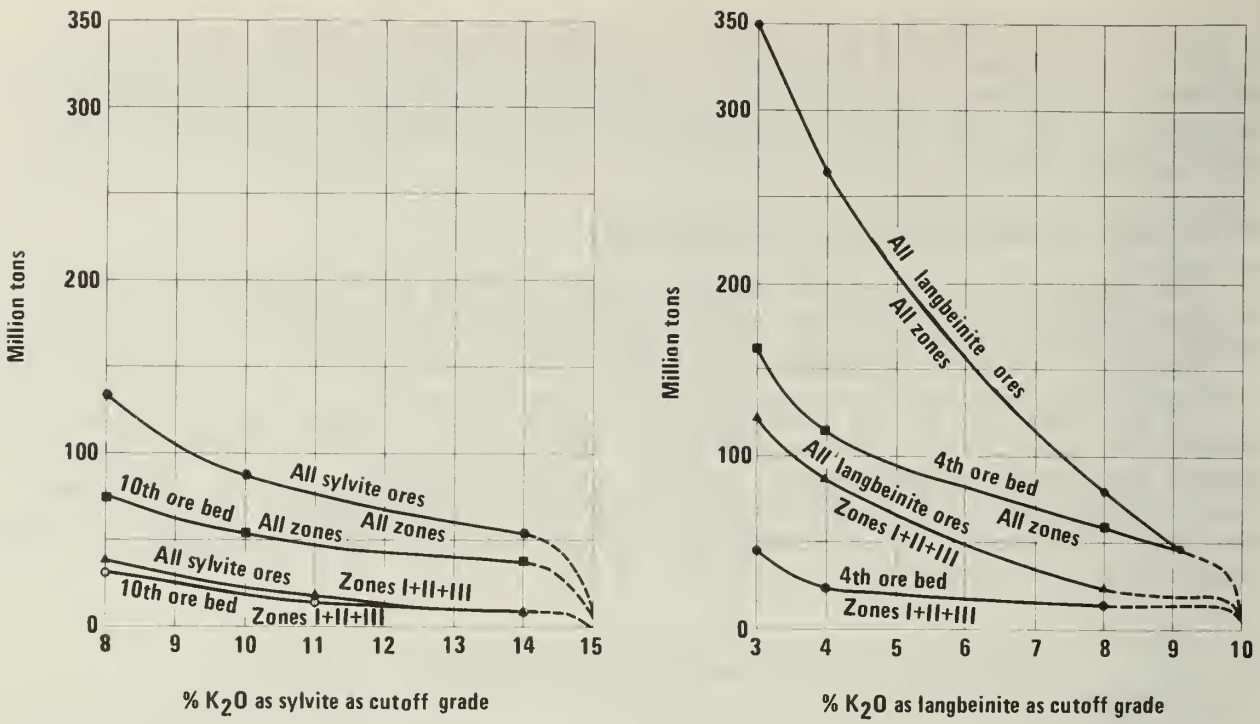
The results of the evaluation have been released by the USGS and are summarized in Table 7-6 (see John et al., 1978, for full details). Figure 7-16 shows how the amounts of these resources depend on the grade criteria used.

In the Carlsbad Potash Mining District, which is adjacent to the site, commercial quantities of potassium salts are restricted to the middle portion, called the McNutt Potash Member, of the Salado Formation. A total of 12 horizons or beds have been recognized in the McNutt Potash Member. Number 1 is at the base, and Number 12 is at the top. These ore bed numbers are used in describing potash resources in Table 7-6.

Table 7-6 Potash Resources (Millions of Tons)[a]

Ore bed	Low grade	Lease grade	High grade
	SYLVITE ORES		
10	74.8	53.7	38.7
9	10.3	6.0	0.7
8	48.1	28.8	13.7
Total	133.2	88.5	53.1
	LANGBEINITE ORES		
10	55.6	49.4	8.8
5	26.2	24.2	1.6
4	161.0	115.4	59.0
3	34.5	25.6	--
2	73.7	50.2	9.8
Total	351.0	264.8	79.2
	ALL ORES		
10	130.4	103.1	47.5
9	10.3	6.0	0.7
8	48.1	28.8	13.7
5	26.2	24.2	1.6
4	161.0	115.4	59.0
3	34.5	25.6	--
2	73.7	50.2	9.8
Total	484.2	353.3	132.3

[a]Data from John et al. (1978), Table 4.



Data from John et al. (1978).

Figure 7-16. Sylvite and langbeinite resources at the site.

Estimates of total resources are considered to be accurate because of the density of exploratory drilling in the site and nearby areas. The data base exceeds both in quality and in quantity that available to other investigators who have estimated national or worldwide resources.

Methods used to determine potash reserves at the WIPP reference site

At the request of the DOE the U.S. Bureau of Mines (USBM) undertook the task of determining potash reserves, using resource calculations and maps provided by the USGS resource study. The method of determining to what extent the deposits could be mined consisted of designing conceptual models for exploiting the deposits. Models ranged from new mines and refineries to mines that merely send the new ore to existing refineries. Shaft locations were selected to minimize underground development and allow mining of the richest ore beds first. The latter is important to quick recovery of invested capital.

Costs were either estimated or, when available, matched to known cost experience at nearby mines. All costs, including construction, were used in discounted cash-flow analysis to determine the market price for refined products guaranteeing a 15% rate of return on invested capital. Federal, State, and local taxes and royalties were taken into account.

In all, the USBM conceived 12 different conceptual plans (which it has termed mining units) for exploiting the potash deposits in the reference site. Of these, eight were fully evaluated and four discarded because of complex problems related to the beneficiation of raw ore.

Results of the potash-reserve determination

The full findings of the reserve evaluation have been reported (USBM, 1977) and are summarized in Table 7-7. The eight mining units that were conceived and then costed are listed in the approximate order in which they would rank as potentially minable.

Table 7-7. Review of USBM Potash Evaluation

Mining unit	Product	Recoverable ore (10^6 tons)	
		In mining unit	In site
B-1	Langbeinite	79.78	48.46
A-1	Muriate	57.60	27.41
D-2	Langbeinite	87.93	23.57
A-2	Muriate	98.32	51.80
C-2	Muriate	57.19	36.49
D-3	Langbeinite	140.27	42.45
C-3	Muriate	70.64	52.87
A-3	Muriate	135.02	73.77

Only mining unit B-1 meets today's market prices ($42 per ton of muriate, $84 per ton of "sulfate" (K_2SO_4), and $48 per ton of langbeinite). This particular reserve consists of langbeinite, mostly in the ore bed 4 in the northwest quadrant of the site. Unit A-1 does not meet the requirements of today's market price; however, the market price of muriate has exceeded $52 per ton in the recent past, at which point the A-1 deposit would be considered a borderline or "potentially economic" deposit. The deposit consists of sylvite contained in the ore bed 10 and located on the west side of the reference site.

Review of methods used to determine the hydrocarbon resources at the WIPP reference site

The New Mexico Bureau of Mines and Mineral Resources (NMBM&MR) has completed a hydrocarbon-resource study in southeastern New Mexico under contract to the Oak Ridge National Laboratory (Foster, 1974). The study included an area equivalent to almost 1 million square miles (Figure 7-17). At the time of that study, the proposed site was about 5 miles northeast of the current site. The NMBM&MR evaluation included a more detailed study of a four-township area centered on the old site; the present site is in the southwest quadrant of that area (Figure 7-17).

The resource evaluation was based on both the known reserves of crude oil and natural gas in the region and the probability of discovering new reservoirs in areas where past wildcat drilling was either too widely spread or too shallow to have allowed discovery. All potentially productive zones were considered in the evaluation; therefore, the findings are valid for determining the total hydrocarbon resources. The fundamental assumption that these resources exist can be fully tested only by drilling in spacings close enough to satisfy the probability of discovery and provide high efficiency of recovery.

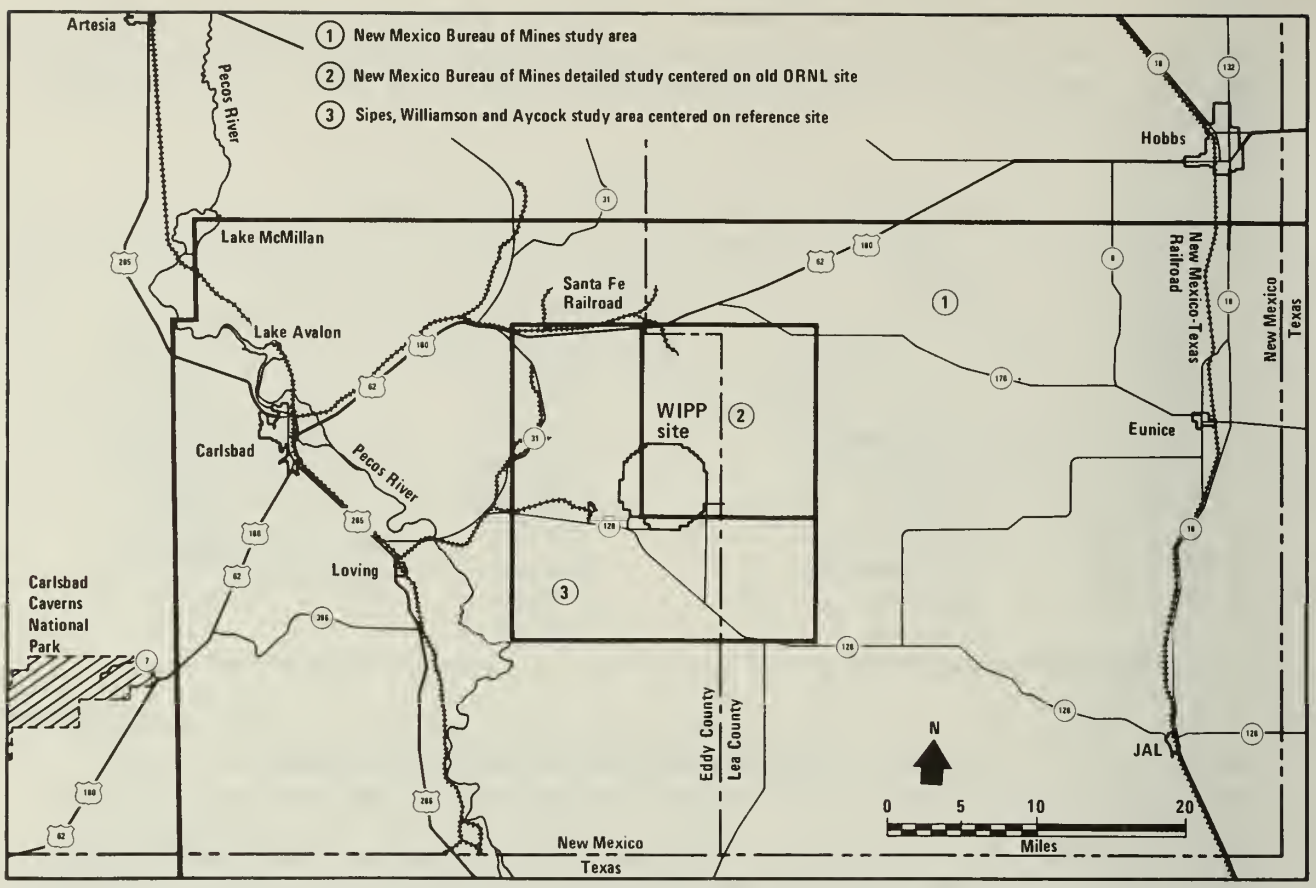


Figure 7-17. Location of hydrocarbon-resource study areas.

Results of the hydrocarbon-resource evaluation

Table 7-8 summarizes the findings of the NMBM&MR hydrocarbon evaluation as the potential resource of hydrocarbons that probably exist under a square mile (640 acres) with the typical geologic and stratigraphic section of that region. The New Mexico Bureau of Mines and Mineral Resources examined an area of 967,680 acres (1512 square miles). The hydrocarbon resources under the site are then estimated as the proportion of the total in the 29.625 square miles of the site (Table 7-9).

Hydrocarbon-resource quantities given in Table 7-9 are equivalent to potash-resource-quantity estimates in that both relate to the quantity of what is present and not to its economic value. Because the hydrocarbon-resource evaluation relies on statistical probability, it is not as accurate as the potash-resource evaluation. The potash resources were actually drilled, while the hydrocarbon resources were estimated by projecting historic drilling success into an untested area. Site-selection requirements dictated that the inner zones be free of deep holes (i.e., oil and gas tests).

Table 7-8. Potential Hydrocarbon Resources Expected in Various Formations in the Delaware Basin[a]

Formation	Adjusted production estimate per section (640 acres) Oil (10^6 bbl)	Gas (10^9 ft^3)	Distillate (10^6 bbl)
Ramsey	0.472	0.756	--
Delaware Mountain Group	0.026	0.010	--
Bone Spring	0.145	0.285	--
Wolfcamp	0.016	0.647	0.024
Pennsylvanian	0.265	10.438	0.132
Mississippian	--	--	--
Silurian/Devonian	0.342	4.408	0.037
Ordovician	--	--	--
TOTAL	1.266	16.544	0.193

[a]Data from Foster (1974). In the original, Foster distinguished between "dry" and "associated" gas. The two types have been summed for simplicity. The estimates for each stratigraphic unit were derived by dividing the total reserves for that unit by the number of acres that have been fully explored, both producing and found dry. Foster also calculated expected resources by another method, based on the success ratio of "wildcat" wells. The wildcat method resulted in lower expected resources; hence, the resources reported here are the larger of the two estimates.

Table 7-9. In-Place Hydrocarbon Resources at the Site[a]

Formation	Oil (10^6 bbl)	Gas (10^9 ft^3)	Distillate (10^6 bbl)
Ramsey	13.98	22.40	--
Delaware Mountain Group	0.77	0.30	--
Bone Spring	4.30	8.44	--
Wolfcamp	0.47	19.17	0.71
Pennsylvanian	7.85	309.22	3.91
Mississippian	--	--	--
Silurian/Devonian	10.13	130.59	1.10
Ordovician	--	--	--
TOTAL	37.50	490.12	5.72

[a]Product of estimate given in Table 7-8 and the number of sections in the reference site (29.625).

Methods used to determine hydrocarbon reserves

The consulting petroleum engineering firm of Sipes, Williamson, and Aycock, Inc. (SW&A) performed the study of economic reserves under contract to Sandia Laboratories (Keesey, 1976). Because there has been no actual drilling within control zones I through III, the study relied on information gained from nearby drilling. To this extent the reserve evaluation followed that for resources. SW&A engineers studied a 400-square mile area centered on the site (Figure 7-17). Unlike the resource study, the reserve evaluation considered economic factors. Drilling and completion costs were balanced against expected recoverable reservoir volumes and delivery rates to arrive at a breakeven point. Exploratory drill sites were selected with the benefit of seismic surveys that had been completed at the site during the course of site evaluation (G. J. Long and Associates, 1976).

Results of the hydrocarbon-reserve estimate

The study of resources by NMBM&MR indicate that as many as 15 potential productive horizons ("pay zones") exist within the eight major stratigraphic divisions that underlie the evaporite deposits. Economic analysis revealed that only a single zone, the Morrow Formation of Pennsylvanian age, is worthy of exploration risk. The Morrow is a fairly consistent natural-gas producer over much of this area. Twenty hypothetical drilling sites were selected to develop the gas expected in the Morrow (Figure 7-18). Locations were selected

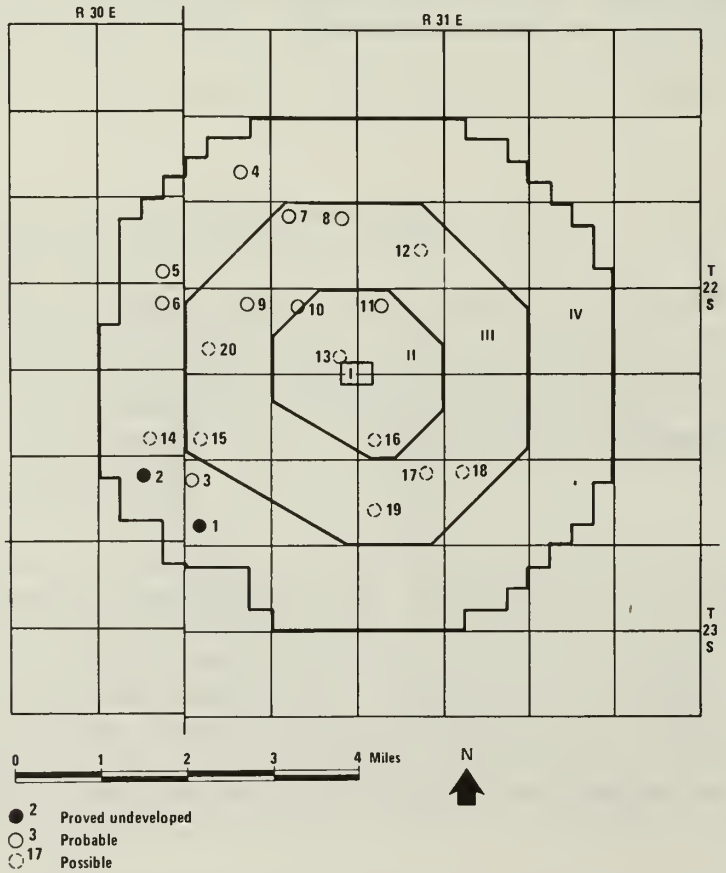


Figure 7-18. Hypothetical drilling sites to develop potential Morrow gas reservoirs.

Table 7-10. Estimate of Natural Gas Reserves at the Reference Site (Billions of Cubic Feet)

Well number	Zones I, II, III			Zone IV			Total		
	Proved	Probable	Possible	Proved	Probable	Possible	Proved	Probable	Possible
1	---	---	---	2.07	---	---	2.07	---	---
2	---	---	---	2.07	---	---	2.07	---	---
3	---	---	---	---	1.64	---	---	1.64	---
4	---	---	---	---	2.09	---	---	2.09	---
5	---	---	---	---	2.09	---	---	2.09	---
6	---	---	---	---	2.09	---	---	2.09	---
7	---	2.09	---	---	---	---	---	2.09	---
8	---	2.09	---	---	---	---	---	2.09	---
9	---	2.09	---	---	---	---	---	2.09	---
10	---	2.09	---	---	---	---	---	2.09	---
11	---	2.09	---	---	---	---	---	2.09	---
12	---	---	1.67	---	---	---	---	---	1.67
13	---	---	1.67	---	---	---	---	---	1.67
14	---	---	---	---	---	1.33	---	---	1.33
15	---	---	1.33	---	---	---	---	---	1.33
16	---	---	1.67	---	---	---	---	---	1.67
17	---	---	1.67	---	---	---	---	---	1.67
18	---	---	1.67	---	---	---	---	---	1.67
19	---	---	1.67	---	---	---	---	---	1.67
20	---	---	1.67	---	---	---	---	---	1.67
Subtotal	---	10.45	13.02	4.14	7.91	1.33	4.14	18.36	14.35
Total			23.47			13.38			36.85
	Plus distillate 351,000 bbl			Plus distillate 200,000 bbl			Plus distillate 551,000 bbl		

on the basis of geologic structure. Estimated reserves that ranged from 1.33 billion to 2.09 billion cubic feet were assigned to each well. The highest reserves were assigned to wells that either were direct offsets to known Morrow gas producers or contained the combination of favorable geologic structure with chances of encountering shallower pay zones on drilling down to the Morrow. Reserves expected under the site are summarized in Table 7-10. The total natural gas reserve is 36.85 billion cubic feet. Some natural gas liquids (distillate) can be expected to be associated with the gas. The NMBM&MR study of several Morrow gas fields revealed that such gas is accompanied by 14,950 barrels of distillate per billion cubic feet of gas. Therefore, 551,000 barrels of distillate should exist under the site.

7.2.8 Soils

The section discusses the physical and chemical characteristics and distribution of soil types in the region of the reference site. The biological aspects of soils, such as fertility and productivity, are described in Appendix H.

The soils of the region have developed mainly from Quaternary and Permian parent material. Parent material from the Quaternary system is represented by alluvial deposits of major streams, dune sand, and other surface deposits. These are mostly loamy and sandy sediments containing some coarse fragments. Parent material from the Permian system is represented by limestone, dolomite, and gypsum bedrock.

Soils of the region have developed in a semiarid, continental climate with abundant sunshine, low relative humidity, erratic and low rainfall, and a wide variation in daily and seasonal temperatures.

The prevailing climate and vegetation have caused many soils of the region to develop a light-colored surface. Subsoil colors normally are light brown to reddish brown, but are often mixed with white lime accumulations (caliche), which result from limited, erratic rainfall and insufficient leaching.

The soil descriptions presented here are based on a soil survey of the Eddy area (Soil Conservation Service, 1971) and have been verified by studies in the field.

The soil associations of Eddy and Lea Counties and the site vicinity (5-mile radius) are mapped in Figure 7-19. A soil association is a landscape that has a distinctive pattern of soil types (series). It normally consists

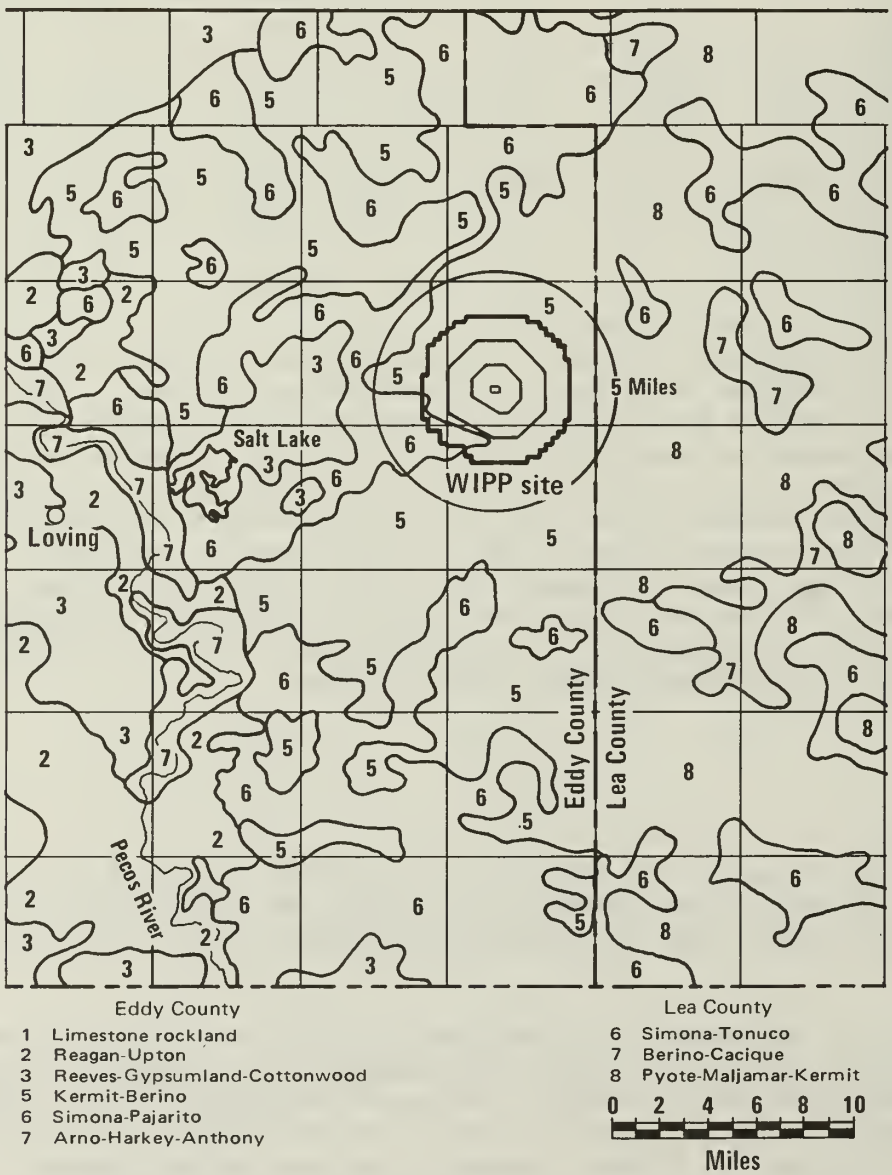


Figure 7-19. Soil-associations map for Eddy and Lea Counties.

of one or more major soils and at least one minor soil. The three soil associations within 5 miles of the site are

Association	Description	Occurrence (%)
1	Kermit-Berino: sandy, deep soils from wind-worked mixed sand deposits	82
2	Simona-Pajarito: sandy, deep soils and soils that are shallow to caliche; from wind-worked deposits	14
3	Pyote-Maljamar-Kermit: gently undulating and rolling deep, sandy soils	4

Of these three associations, only the Kermit-Berino occurs at the site, in control zones I and II, and consists of two soil series, the Berino and the Kermit. These soils are mapped in Figure 7-20; Tables 7-11, 7-12, and 7-13 give typical soil profiles and detailed physical, engineering, and chemical characteristics.

Generally, the Berino series, which covers about 50% of the site, consists of deep, noncalcareous, yellow-red to red sandy soils that developed in wind-worked material of mixed origin. These soils occur as gently sloping (0 to 3% slopes) undulating to hummocky areas and are the most extensive of the deep, sandy soils in the Eddy area. Berino soils are subject to continuing wind and water erosion. If the vegetative cover is seriously depleted, the water erosion potential is slight but the wind erosion potential is very high. These soils are particularly sensitive to wind erosion in the months of March, April, and May, when rainfall is minimal and winds are highest. Permeability is high in the surface layer but moderately low in the subsoil. Chemical analyses suggest the soils are typical of nonirrigated, semiarid soils with no unusual chemical properties. The concentrations of soluble potassium and chloride ions are not especially great, despite the proximity of the study area to potash mines.

The typifying profile (moist colors) is as follows:

A^1	0-47.5 cm (0-19 inches)	Yellowish-red (5YR 4/4) fine sand; weak, moderate subangular blocky structure; soft; very friable; nonsticky, nonplastic; abrupt and smooth boundary.
$B_{21}t$	47.5-70.0 cm (19-28 inches)	Yellowish-red (5YR (4/4) sandy loam; weak, coarse, prismatic structure; hard; firm; slightly sticky; nonplastic; abrupt and smooth boundary.
$B_{22}t$	70.0-100 cm (28-40 inches)	Red (2.5YR 4/4) sandy clay laom, moderate, coarse, prismatic structure; very hard; firm; sticky; plastic; clear and smooth boundary.
B_3	100-117.5 cm (40-47 inches)	Red (2.5YR 4/4) light sandy clay loam; weak subangular blocky structure; hard; firm; sticky; plastic; abrupt and smooth boundary.
C_{Ca}	117.5-137.5 cm (47-55 inches)	Pink (5YR 6/4) light clay loam; massive; extremely hard; firm; sticky; plastic; strongly calcareous.

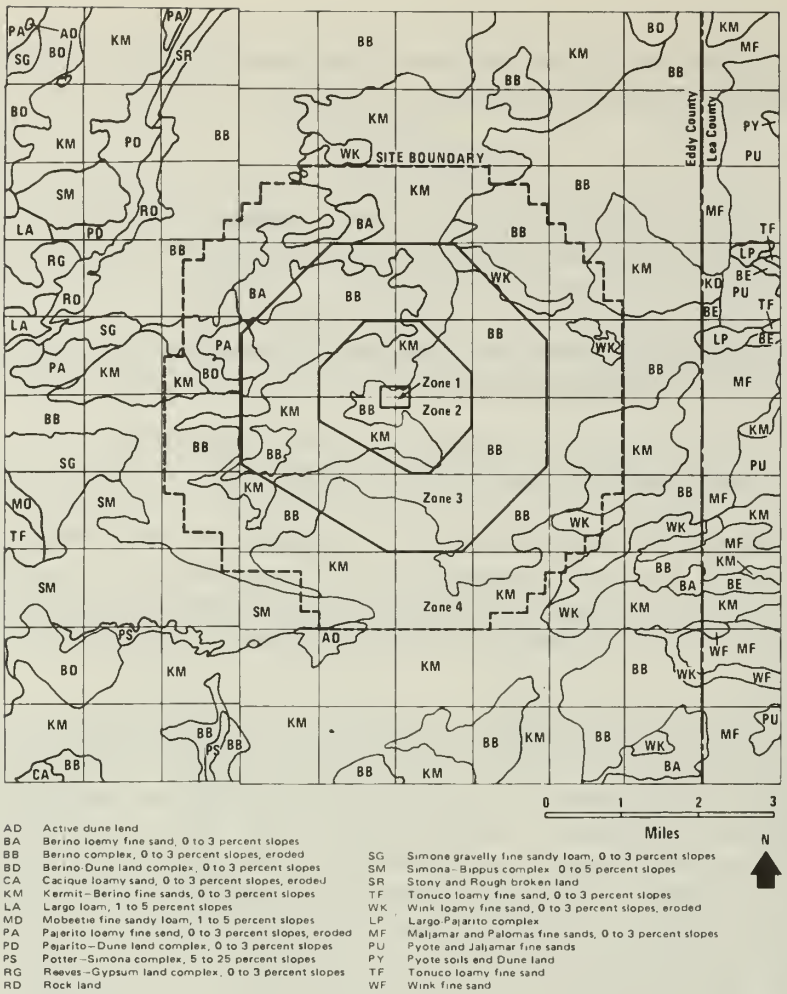


Figure 7-20. Soil-series map.

Generally, the Kermit series, which covers about 50% of the site, consists of deep, light-colored, noncalcareous, excessively drained loose sands, typically yellowish-red fine sand. The surface is undulating to billowy (0 to 3% slopes) and consists mostly of stabilized sand dunes. Kermit soils are slightly to moderately eroded. Permeability is very rapid, and if vegetative cover is removed, the water erosion potential is slight but the wind erosion potential is very high. Chemical analyses suggest the soils are typical of nonirrigated, semiarid soils with no unusual chemical properties. The concentrations of soluble potassium and chloride ions are not especially great despite the proximity of the study area to potash mining.

The typifying profile (moist colors) is as follows:

A_1	0-15 cm (0-6 inches)	Yellowish-red (5YR 4/4) fine sand; single grain; loose when dry or moist; nonsticky; noncalcareous; clear and smooth boundary.
C	15-162.5 cm (6-65 inches)	Yellowish-red (5YR 4/4) fine sand; single grain; loose when dry or moist; nonsticky, nonplastic; noncalcareous.

Table 7-11. Estimated Properties, Characteristics, and Engineering Suitability of Soils at the Site[a]

Property	Soil sample depth (cm)		
	Berino		Kermit
	0-17	17-50	0-60
ESTIMATED PROPERTIES AND CHARACTERISTICS			
Depth to bedrock or hard caliche (in.)	More than 60		More than 60
Classification			
USDA (texture)	Fine sand and fine sandy loam		Fine sand
Unified	SM	SC	SP-SM
AASHO	A-2	A-6	A-3
Percentage passing sieve:			
No. 4 (4.7 mm)	100	100	100
No. 10 (2.0 mm)	100	100	100
No. 200 (0.074 mm)	10-20	35-45	5-10
Permeability (in./hr)	5.0-10.0	0.2-0.8	10.0
Availabie water capacity (in./in. soil)	0.06-0.08	0.14-0.16	0.06-0.08
Reaction (pH)	6.6-7.3	6.6-7.3	6.6-7.3
Electrical conductivity (10^3 mmhos/cm at 25°C)	0-1.0	0-4.0	0-1.0
Corrosivity (untreated steel pipe)	Low	Moderate	Low
Shrink-swell potential	Low	Moderate	Low
Erodibility			
Water erosion (K factor)	0.17 (slight potential)		0.15 (slight potential)
Wind erosion (I factor)	134-220 (very high potential)		220 (very high potential)
ESTIMATES OF THE SUITABILITY OF THE SOILS FOR SPECIFIED USES			
Suitability as a source of			
Topsoil	Poor		Poor: drifting sand
Road fill	Poor to fair		Good if soil binder is added
Degree of limitation for disposal fields for septic tanks and tile systems	Severe: moderately slow permeability; soft caliche at a depth of 50 in.		Slight: drifting sand
Highway location	Features favorable		Loose sand hinders hauling; drifting sand embankments highly erodible
Dikes and levees	Sandiness of surface material necessitates mixing with subsoil material		Not applicable
Farm ponds and embankments	Susceptible to piping; moderate seepage; sandy, porous surface		Not applicable
Irrigation	Rapid intake rate; smoothing necessary; susceptible to wind erosion		Not applicable
Leveling and benching	Soft caliche at a depth of 50 in.; highly susceptible to wind erosion		Not applicable
Foundations for low buildings	Good bearing capacity		Good suitability if soil is confined
Pipelines	Features favorable		Subject to blowouts
Hydrologic group	A		A

[a]Data from the Soil Conservation Service (1971).

Table 7-12. Physical and Chemical Properties of the Berino (BA and BB) Soil Series at the Site[a]

Property	Soil sample depth (cm)				
	Berino loamy fine sand (BA)		Berino complex (BB)		
	0-10	25-50	0-10	25-50	62.5-87.5
CHEMICAL PROPERTIES					
pH	7.40	7.20	7.37	7.25	7.12
Electrical conductivity, mmhos/cm	0.21	0.15	0.26	0.14	0.18
Water-soluble ions, meq/l					
Calcium	1.09	0.89	2.01	0.83	1.09
Magnesium	0.35	0.22	0.46	0.25	0.47
Sodium	0.12	0.11	0.08	0.12	0.14
Potassium	0.33	0.07	0.30	0.12	0.12
Chloride	0.27	0.60	0.12	0.17	0.28
Sulfate	0.22	0.18	0.07	0.18	0.37
Bicarbonate	1.45	0.62	2.81	0.99	1.73
Boron, ppm	0.07	0.10	0.09	0.12	0.10
Nitrate, ppm	1.92	4.17	2.04	3.32	1.18
Phosphate, ppm	0.03	0.01	0.07	0.01	0.01
Exchangeable cations, meq/100 g					
Calcium	2.58	3.26	2.42	2.52	7.22
Magnesium	0.56	0.59	0.38	0.48	2.03
Sodium	0.07	0.11	0.09	0.02	0.05
Potassium	0.29	0.18	0.03	0.18	0.41
Cation-exchange capacity, meq/100 g	3.50	4.14	3.12	3.20	9.71
Gypsum, %	0	0	0	0	0
Calcium carbonate %	0	0	0	0	0
Organic matter, %	0.26	0.16	0.36	0.20	0.20
Total nitrogen, %	0.02	0.01	0.02	0.01	0.02
PHYSICAL PROPERTIES					
Hydraulic conductivity, cm/hr	36.2	24.1	41.9	28.8	12.8
Available moisture[b]	1.0	0.7	0.7	0.6	2.8
Texture	Fine sand	Fine sand	Fine sand	Fine sand	Fine sandy loam
Sand, %	91.54	91.52	94.15	93.35	79.45
Coarse (2-0.5 mm), %	5.39	1.80	2.12	1.83	2.29
Medium (0.5-0.25 mm), %	17.85	12.18	24.54	24.65	23.06
Fine (0.25-0.05 mm), %	68.30	76.54	67.49	66.89	54.10
Silt, %	5.40	4.56	4.72	3.88	6.20
Clay, %	3.06	3.92	1.13	2.78	14.35

[a]Data from Wolfe et al. (1977).

[b]Available moisture determined as the difference in percent moisture at tensions of 1/3 and 15 bars.

Table 7-13. Physical and Chemical Properties of the Kermit (KM) Soil Series at the Site[a]

Property	First sampling site (cm) 0-10	First sampling site (cm) 25-50	Second sampling site (cm) 0-10	Second sampling site (cm) 25-50
CHEMICAL PROPERTIES				
pH	7.42	7.44	7.39	7.45
Electrical conductivity, mmhos/cm	0.19	0.16	0.12	0.09
Water-soluble ions, meq/l				
Calcium	1.37	1.10	0.54	0.61
Magnesium	0.25	0.25	0.15	0.16
Sodium	0.12	0.11	0.12	0.09
Potassium	0.28	0.18	0.17	0.10
Chloride	0.12	0.03	0.08	0.01
Sulfate	0.18	0.11	0.37	0.37
Bicarbonate	1.70	1.92	0.49	1.01
Boron, ppm	0.28	0.12	0.27	0.07
Nitrate, ppm	16.23	0.77	14.98	2.11
Phosphate, ppm	0.37	0.01	0.15	0.01
Exchangeable cations, meq/100 g				
Calcium	1.81	1.52	1.06	1.54
Magnesium	0.29	0.26	0.23	0.27
Sodium	0.17	0.03	0.03	0.02
Potassium	0.16	0.14	0.12	0.12
Cation-exchange capacity, meq/100 g	2.43	1.96	1.44	1.95
Gypsum, %	0	0	0	0
Calcium carbonate, %	0	0	0	0
Organic matter, %	0.16	0.13	0.13	0.16
Total nitrogen, %	0.01	0.01	0.01	0.01
PHYSICAL PROPERTIES				
Hydraulic conductivity, cm/hr	51.6	37.5	51.2	41.0
Available moisture[b]	0.3	0.3	0.5	0.3
Texture:	Coarse sand	Fine sand	Fine sand	Fine sand
Sand, %	97.47	96.16	97.51	96.26
Coarse (2-0.5 mm), %	62.63	1.65	3.02	1.90
Medium (0.5-0.25 mm), %	26.36	19.51	34.77	28.25
Fine (0.25-0.05 mm), %	8.48	75.00	59.72	66.11
Silt, %	0.61	2.52	0.15	2.77
Clay, %	1.92	1.32	2.35	0.97

[a]Data from Wolfe et al. (1977).

[b]Available moisture determined as the difference in percent moisture at tensions of 1/3 and 15 bars.

The WIPP reference site is in the southwestern portion of the Permian basin, within the surface-water boundaries of the Rio Grande Water Resources Region. The site and surrounding land drain into the Pecos River. Two major groundwater regions are included in the Permian basin: the High Plains and the Unglaciated Central regions. The site lies within the Delaware basin, a portion of the Unglaciated Central region that includes some of the least productive aquifers in the United States.

There are no perennial streams or surface-water impoundments on the site, nor are there any wells yielding more than a few gallons per minute. The climate is semiarid, with a mean annual precipitation of about 12 inches, a mean annual runoff of 0.1 to 0.2 inch, and a mean annual pan evaporation of more than 100 inches. Unlike the productive terrace-alluvium Ogallala aquifer east of the site, the main Unglaciated Central aquifers are limestone and sandstone formations of low to moderate productivity. Brackish water with total-dissolved-solids (TDS) concentrations of more than 3000 parts per million (ppm) is common from shallow wells used for watering livestock. Surface waters have typically high TDS concentrations, particularly chloride, sulfate, sodium, magnesium, and calcium.

At the site, hydrologic data have been obtained from conventional and special-purpose test configurations in 21 drilled holes. Geophysical logging of the open boreholes has provided hydrologic information on the rock strata intercepted. Pressure measurements, fluid samples, and indications of rock permeability have been obtained for selected formations through the use of standard and modified drill-stem tests. The recovery of liquid levels in the drill holes after the removal of a known amount of fluid (bailer test) has provided additional data to aid in the estimation of aquifer parameters. Potentiometric surfaces have been mapped from measured heights of water in the holes, and the integrity of cement bonds in deep-hole construction has been verified with radioactive-tracer tests.

7.3.1 Surface-Water Hydrology

The proposed site is in the Pecos River basin, which contains about 50% of the drainage area of the Rio Grande Water Resources Region. The Pecos River headwaters are northeast of Santa Fe, and the river flows southeasterly through eastern New Mexico and western Texas to the Rio Grande. The Pecos River has an overall length of about 500 miles, a maximum basin width of about 130 miles, and a total drainage area of about 44,535 square miles (about 20,500 square miles are noncontributing). Its principal tributaries, in downstream order, are the Gallinas River, Salt Creek, Rio Hondo, Rio Felix, Eagle Creek, Rio Penasco, the Black River, and the Delaware River.

Regional water quantity

The Pecos River is generally perennial, except in the reach below Anton Chico and between Fort Sumner and Roswell, where the low flows percolate into

the stream bed. The main stem of the Pecos River and its major tributaries have low flows (Table 7-14), and the streams are frequently dry. About 75% of

Table 7-14. Discharge in the Pecos River Basin Within or Adjacent to the Permian Basin[a]

River	Location	Drainage area (miles^2)	Period of record	Discharge (cfs) Average	Minimum	Maximum
Pecos	Santa Rosa, N. Mex.	2,650	1912-75	138	0.3	55,200
Pecos	Acme, N. Mex.	11,380	1937-75[b]	194	0	45,000
Pecos	Artesia, N. Mex.	15,300	1936-75[b]	265	0	51,500
Pecos	Malaga, N. Mex.	19,190	1936-75[b]	196	5	120,000
Pecos	Orla, Tex.	21,210	1937-75[b]	181	0	23,700
Pecos	Girvin, Tex.	29,560	1939-75[b]	96	2.2	20,000
Rio Hondo	Roswell, N. Mex.	963	1963-75	9	0	659
Rio Felix	Hagerman, N. Mex.	932	1939-75	16	0	74,000
Rio Penasco	Dayton, Tex.	1,060	1951-75	6	0	29,000
Black	Malaga, N. Mex.	343	1947-75	14	0.7	74,600
Delaware	Red Bluff, Tex.	689	1937-75	14	0	81,400

[a]Data from USGS (1976).
[b]Flow regulated.

the total annual precipitation and 60% of the annual flow occur between April and September, from intense local thunderstorms.

The mean annual precipitation in the site region is about 12 inches, and the mean annual runoff is 0.1 to 0.2 inch. The maximum recorded 24-hour precipitation was 5.12 inches, in August 1916. The 6-hour, 100-year precipitation event for the site is 3.6 inches and is most likely during the summer. The maximum daily snowfall at Carlsbad was 10 inches, in December 1923.

The maximum recorded flood on the Pecos River near Malaga occurred on August 23, 1966, with a discharge of 120,000 cubic feet per second (cfs) and a stage elevation of about 2938 feet above mean sea level (USGS Station No. 08406500). The minimum surface elevation for the proposed site is approximately 312 feet above this maximum historical flood elevation.

More than 90% of the mean annual precipitation at the site is expected to be lost to evapotranspiration. Table 7-15 shows the mean monthly temperature for Artesia, the mean monthly pan evaporation for Lake Avalon, and the mean monthly rainfall at Carlsbad. On a mean monthly basis, evapotranspiration at the site greatly exceeds the available rainfall; however, intense local thunderstorms produce runoff and percolation. Water-infiltration rates in the local sand dunes are probably similar to the 1.6-inch-per-hour intake rate of Harkey sandy loam (75% sand) near Carlsbad (Blaney and Hanson, 1965).

Four major reservoirs are located in the Permian basin: Alamogordo Reservoir, Lake McMillan, Lake Avalon, and Red Bluff Reservoir. The storage capacities of these reservoirs and other Pecos River reservoirs adjacent to the Permian basin are shown in Table 7-16.

Table 7-15. Mean Monthly Temperature, Pan Evaporation, and Rainfall[a]

Month	Mean monthly temperature, Artesia (°C)	Mean monthly pan evaporation, Lake Avalon (cm)	Mean monthly precipitation, Carlsbad (cm)
January	4.89	10.67	1.07
February	7.17	14.63	0.94
March	11.00	23.44	1.18
April	16.06	29.90	1.37
May	20.78	35.69	4.63
June	25.78	37.14	3.37
July	26.67	33.27	3.91
August	26.33	31.50	4.23
September	22.61	24.69	5.08
October	16.72	17.78	4.29
November	9.33	11.46	0.88
December	5.44	13.82	1.20

[a]Data from Blaney and Hanson (1965).

Table 7-16. Major Reservoirs in the Pecos River Basin[a]

Reservoir	River	Total storage capacity[b] (acre-feet)	Use[c]
Los Esteros Lake	Pecos	282,000	FC
Alamogordo Reservoir	Pecos	122,100	IR, R
Lake McMillan	Pecos	33,600	IR, R
Lake Avalon	Pecos	5,000	IR
Red Bluff Reservoir	Pecos	310,000	IR, P
Two River Reservoir	Rio Hondo	167,900	FC

[a]Data from New Mexico State Engineer's Office (1967); U.S. Army Corps of Engineers (1977).
[b]Capacity below the lowest uncontrolled outlet or spillway.
[c]Key: FC = flood control; IR = irrigation; R = recreation; P = hydroelectric.

Regional water quality

Water quality in the Pecos River basin is affected by mineral pollution from natural sources and from irrigation return flows. Springs near the headwaters of the basin below Colonias, New Mexico, discharge approximately 707 tons per day of dissolved solids into the Pecos River. Large amounts of chlorides from Salt Creek and Bitter Creek enter the river near Roswell. River inflow in the Hagerman area contributes increased amounts of calcium, magnesium, and sulfate, and waters entering the river near Lake Arthur are

high in chloride. Below Lake McMillan, springs flowing into the river are usually submerged and difficult to sample; springs that could be sampled had TDS concentrations of 3350 to 4000 ppm. Concentrated brine entering at Malaga Bend adds an estimated 70 tons per day of chloride to the Pecos River (FWPCA, 1967). Time-weighted averages of water-quality parameters for three sampling stations on the Pecos River between Carlsbad and Malaga Bend are shown in Table 7-17.

The potash industry uses 12,000 acre-feet of "fresh water" annually and discharges approximately 10,000 acre-feet of brine effluent (BLM, 1975). The effluent sinks to contaminate brackish aquifers or recharges existing playas. The potash industry also discards more than 3 parts of solid sodium chloride for each part of potassium chloride product. Some 200 million tons of sodium chloride waste piled around the refineries contribute to brine runoff after thunderstorms. Much of the waste-pile and effluent brine discharges to the excess surface flows and ponding in Nash Draw. The slope of the terrain and of shallow aquifers around Nash Draw is toward the Pecos River.

Table 7-17. Water-Quality Parameters (Time-Weighted Averages) for Sampling Stations on the Pecos River, October 1975 to September 1976[a]

Station No.	Discharge (cfs)	pH	Dissolved-solids concentration (ppm)				
			Total	Chloride	Sulfate	Sodium	Calcium
08405000 (Carlsbad)	12	7.7	2,500	531	1100	322	334
08406500 (Near Malaga)	26	7.7	5,390	1690	1820	1030	524
08407000 (Pierce Canyon Crossing)	28	7.5	13,900	6500	2280	4020	551

[a]Data from the U.S. Geological Survey (1977), Water Year October 1975 to September 1976.

Regional water use

The total water-withdrawal rate for the Permian basin in 1975 was about 30,000 million gallons per day (mgd), with about 19,000 mgd coming from groundwater. The total withdrawal for the Upper Pecos and the Rio Grande-Pecos Water Resource Subregions in 1975 was 1771 mgd, of which 1079 mgd, or 63%, came from groundwater. Agriculture, with a withdrawal of 1546 mgd, or 90% of the total, is the most significant user (Table 7-18). Agricultural acreage between Carlsbad and the Red Bluff Reservoir used less than 7% of the total irrigation requirements of the Pecos River basin and less than 1% of the total surface-water and groundwater withdrawals for the Permian basin.

Table 7-18. Water Use in the Upper Pecos and Rio Grande-Pecos Subregions[a]

Use category	Surface-water and groundwater withdrawals (mgd) 1975b	1985	2000
Agriculture	1546	1239	1689
Steam-electricity	12	3	2
Manufacturing	0	0	0
Domestic	47	47	47
Commercial	8	8	8
Mining	151	155	161
Public lands	4	4	4
Fish hatcheries	3	5	7
TOTAL	1771	1461	1918

[a]Data from the U.S. Water Resources Council (in press).
[b]The total groundwater withdrawal for 1975 was 1079 mgd.

Local surface-water hydrology

There are no perennial streams or surface-water impoundments at the proposed site. At its nearest point, the Pecos River is approximately 14 miles southwest of the site center.

The drainage area of the river at this location is 19,000 square miles. A few small creeks and draws are the only westward-flowing tributaries of the Pecos River within 20 miles north or south of the site. From the west, the Black River (drainage area 400 square miles) joins the Pecos about 16 miles southwest of the site. The Delaware River (drainage area 700 square miles) and a number of small creeks and draws join the Pecos along this reach. Pecos River flow below Fort Sumner is regulated by storage in Lake Sumner, Lake McMillan, Lake Avalon, and several other smaller upstream irrigation dams.

There are no major lakes or ponds within 10 miles of the site center. Laguna Gatuna, Laguna Tonto, Laguna Plata, and Laguna Toston are more than 10 miles north of the site and are at or above elevation 3450 feet. Therefore, surface runoff from the site would not flow toward any of them. To the west and northwest, Red Lake, Lindsey Lake, Salt Lake, and a few unnamed ponds are more than 10 miles from the site, at elevations of 3000 to 3300 feet.

7.3.2 Regional Groundwater Hydrology

The site proposed for the reference case lies within the Delaware basin, which contains some of the least productive aquifers in the United States. The only large quantities of potable groundwater are in shallow aquifers of and along the Pecos River. The Delaware basin is bounded by a limestone reef known as the Capitan Formation (Figure 7-21), which is one of the eight rock units important to the hydrogeology of the Delaware basin; the others are the Delaware Mountain Group, the Castile Formation, the Salado Formation, the Rustler Formation, the Dewey Lake Red Beds, the Santa Rosa Sandstone, and the Chinle Formation.

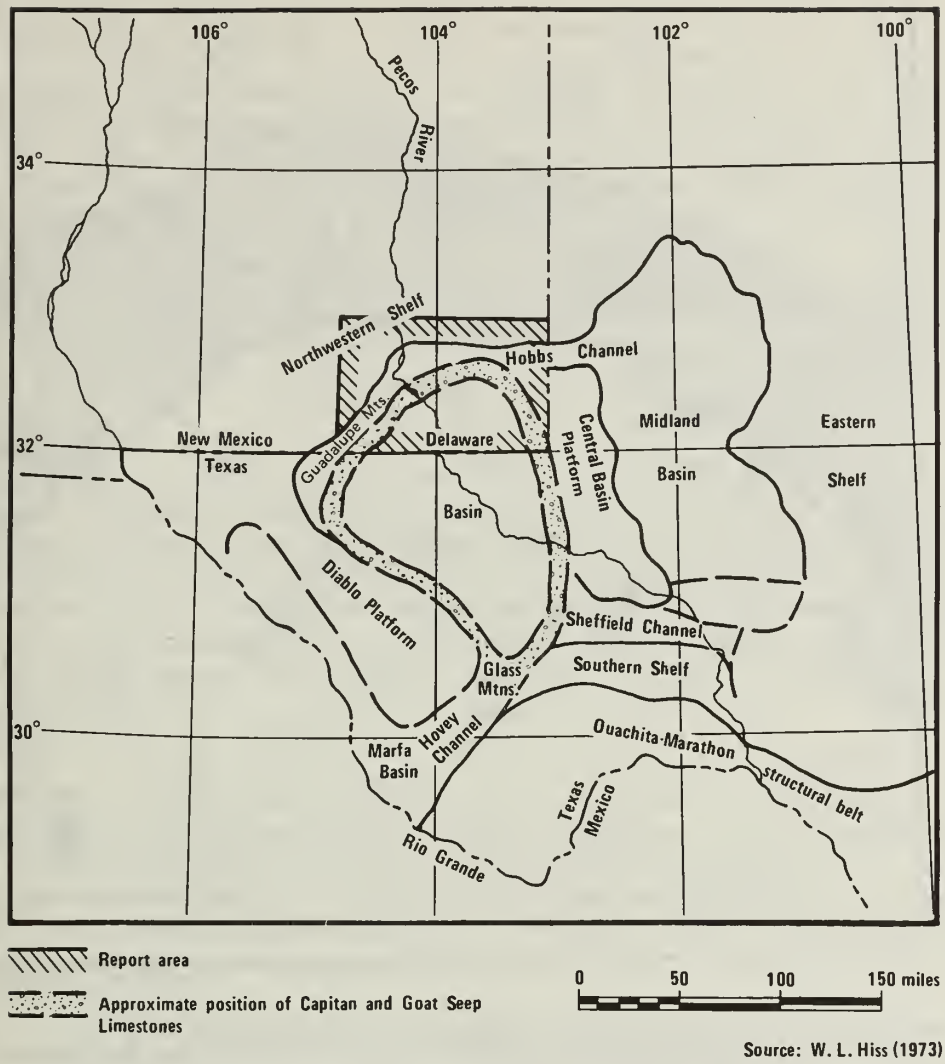
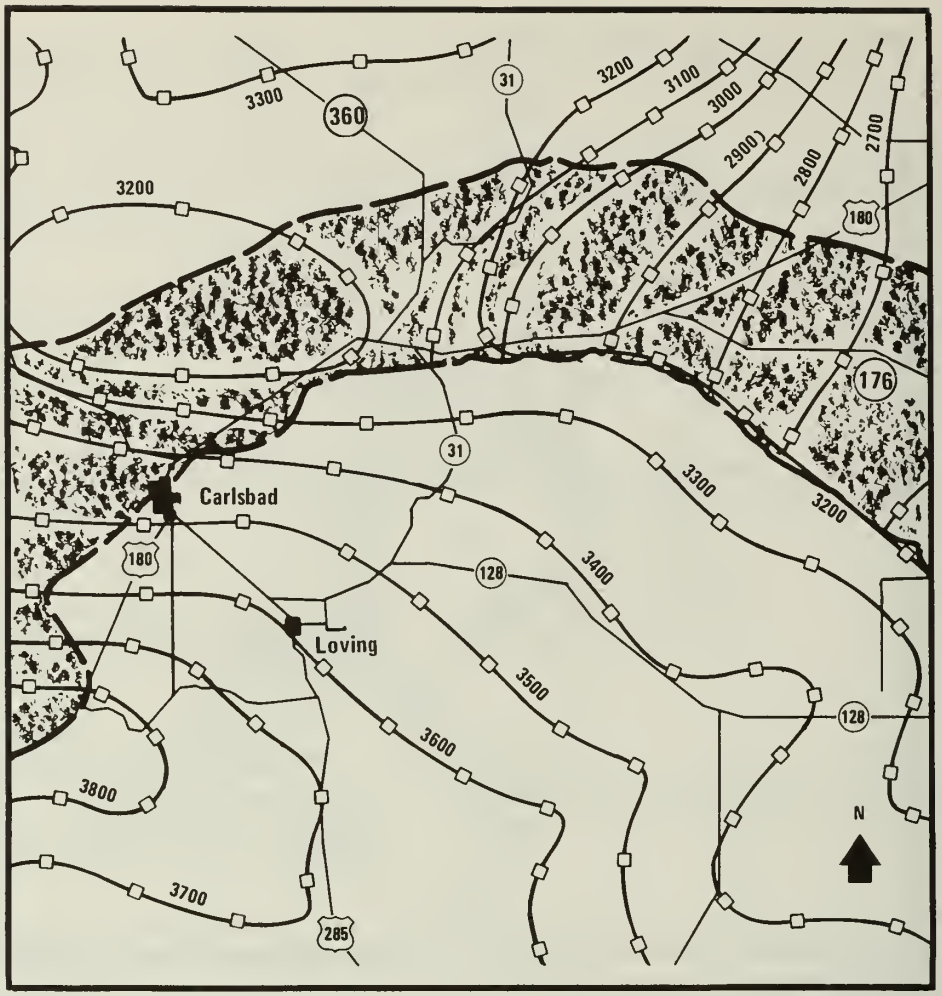


Figure 7-21. Tectonic elements in the Permian basin of western Texas and southwestern New Mexico.

Delaware Mountain Group

Formations of the Delaware Mountain Group underlie the Capitan reef and form the floor of the Delaware basin evaporite sequence. Three separate formations, each about 1000 feet thick, are assumed to form a single aquifer system with an average hydraulic conductivity of 0.016 ft/day, an average porosity of 15.65%, and a calculated transmissivity of about 50 ft^2/day (Powers et al., 1978, p. 6-14). A potentiometric map representing a composite surface for the Delaware Mountain Group (mostly for the Bell Canyon Formation) and Capitan aquifer has been constructed by Hiss (1976). The data were adjusted for the saline density and expressed as a freshwater equivalent. The brines in the Delaware Mountain Group flow northeasterly under a hydraulic gradient of 25 to 40 ft/mile and discharge into the Capitan aquifer (Figure 7-22). Velocities range from 0.2 to 0.3 ft/yr, and groundwater yields from wells in the Delaware Mountain Group are 0.6 to 1.5 gpm.



Source: W. L. Hiss (1976)

Figure 7-22. Potentiometric surface map (composite) below the Castile Formation.

Capitan Limestone

The Capitan Limestone outcrops in the southern end of the Guadalupe Mountains and is a massive limestone unit that grades basinward into recemented, partly dolomitized reef breccia and shelfward into bedded carbonates and evaporites. In Eddy and Lea Counties, it has an average thickness of about 1600 feet. Its hydraulic conductivity ranges from 1 to 25 ft/day and in southern Lea County and east of the Pecos River at Carlsbad is 5 ft/day. Average transmissivities around the northern and eastern margins of the Delaware basin are 10,000 ft^2/day in thick sections and 500 ft^2/day in incised submarine canyons (Hiss, 1976). In the aquifer, water-table conditions are found southwest of the Pecos River at Carlsbad; however, artesian conditions exist to the north and east. A deeply incised submarine canyon near the Eddy-Lea County line has been identified, and the hydraulic gradient to the southeast of this restriction has been attributed to large oil-field withdrawals. The Capitan Limestone is recharged by percolation through the northern shelf aquifers, by flow from underlying basin aquifers to the south and west, and by direct infiltration at the outcrop in the Guadalupe Mountains.

Castile Formation

The Castile Formation separates the Delaware Mountain Group from the Salado Formation. The thickness of the Castile anhydrite unit is 1300 to 2000 feet, and the formation is a confining bed (Lohman et al., 1972), without circulating groundwater. Groundwater flow from the Capitan aquifer and the Delaware Mountain Group toward the Salado is impeded by the low hydraulic conductivity of the Castile. On the western side of the Delaware basin, local cavernous zones near the outcrop of the Castile hold groundwater for stock and domestic use; the water is high in dissolved solids (Bjorklund and Motts, 1959). Drilling in the Castile has found pockets of brine and hydrogen sulfide gas.

Salado Formation

The Salado Formation laps extensively over the back reef of the Capitan Limestone and includes three divisions: the lower salt member, the McNutt Potash Zone, and the upper salt member. It is 1400 to 2100 feet thick and sustains no wells. Although the Salado acts hydrologically as a confining bed and does not contain circulating groundwater, it has pockets of saturated brine and nitrogen gas (Jones et al., 1973).

Rustler Formation

The Rustler Formation contains two water-bearing rock members: the upper Magenta Member and the lower Culebra Dolomite Member. Its thickness is 200 to 600 feet, and the Magenta and Culebra Members are each about 25 feet thick. The Culebra Dolomite Member is the more productive aquifer, but groundwater yields vary considerably with location. In Nash Draw, the Magenta and Culebra Members are in contact.

Figure 7-23 is a potentiometric surface map of the Rustler Formation, mainly of the Culebra Member. The average effective porosity is about 10%, and the calculated transmissivity ranges from 140 to 10^{-4} ft^2/day, the latter at the west edge of the site boundary (Powers et al., 1978, p. 6-36). Gradients range from 7 to 120 ft/mile, depending on hydraulic conductivity. Total dissolved solids in sampled well water from the Rustler Formation are 3000 to 60,000 ppm (Lambert, 1978). Groundwater movement in the Rustler near Los Medanos is westward toward Nash Draw and then southward toward the Pecos River.

Dewey Lake Red Beds

The Dewey Lake Red Beds are a siltstone deposit, some 200 to 600 feet thick, that protects the underlying evaporites (Jones, 1954). Because of their low hydraulic conductivities, the Dewey Lake Red Beds function as a confining bed. Groundwater probably occurs only in sandstone lenses of small capacity.

Santa Rosa Sandstone

The Santa Rosa Sandstone is about 140 to 300 feet thick. It dips gently westward, except in areas of collapse, and crops out northeast of Nash Draw. It has a porosity of about 13% and a specific capacity of 0.14 to 0.2 gpm per foot of drawdown (Nicholson and Clebsch, 1961). Figure 7-24 is a potenti-

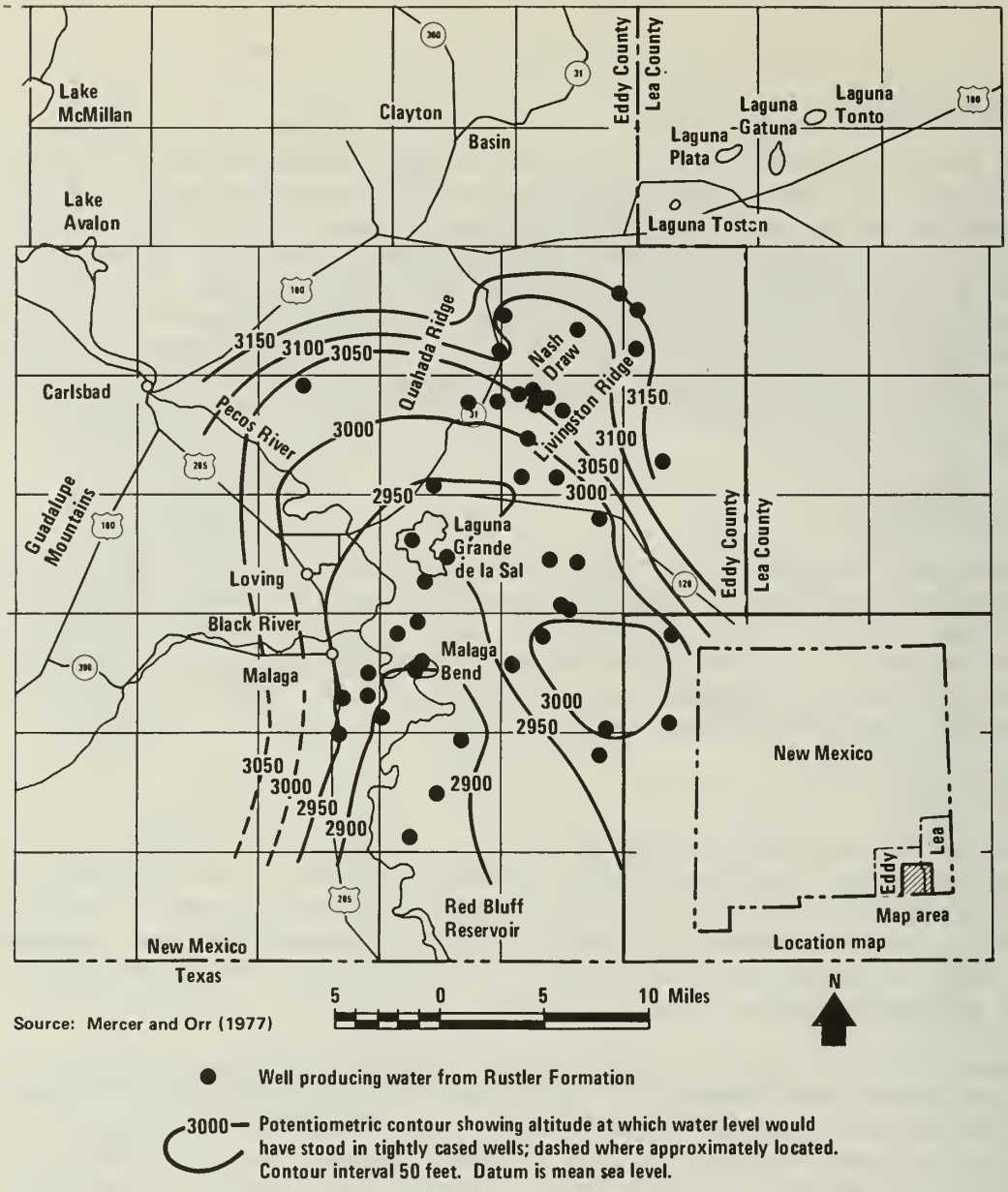


Figure 7-23. Potentiometric surface map of the Rustler Formation.

ometric surface map of the formation. Lows in the potentiometric surface near the Eddy-Lea County line and San Simon Swale suggest recharge into underlying rocks, possibly through collapse zones. In general, groundwater flows south and southwest and is of better quality than that found in the Rustler Formation. The rate of groundwater movement is about 0.3 ft/day.

Chinle Formation

The Chinle Formation is a mudstone deposit above the Santa Rosa Sandstone to the east of the site. It ranges in thickness from about 0 near the Eddy-Lea County line to as much as 800 feet north of San Simon Swale (Mercer and Orr, 1977). Because of the low hydraulic conductivity of mudstone, the Chinle Formation is hydrologically a confining bed.

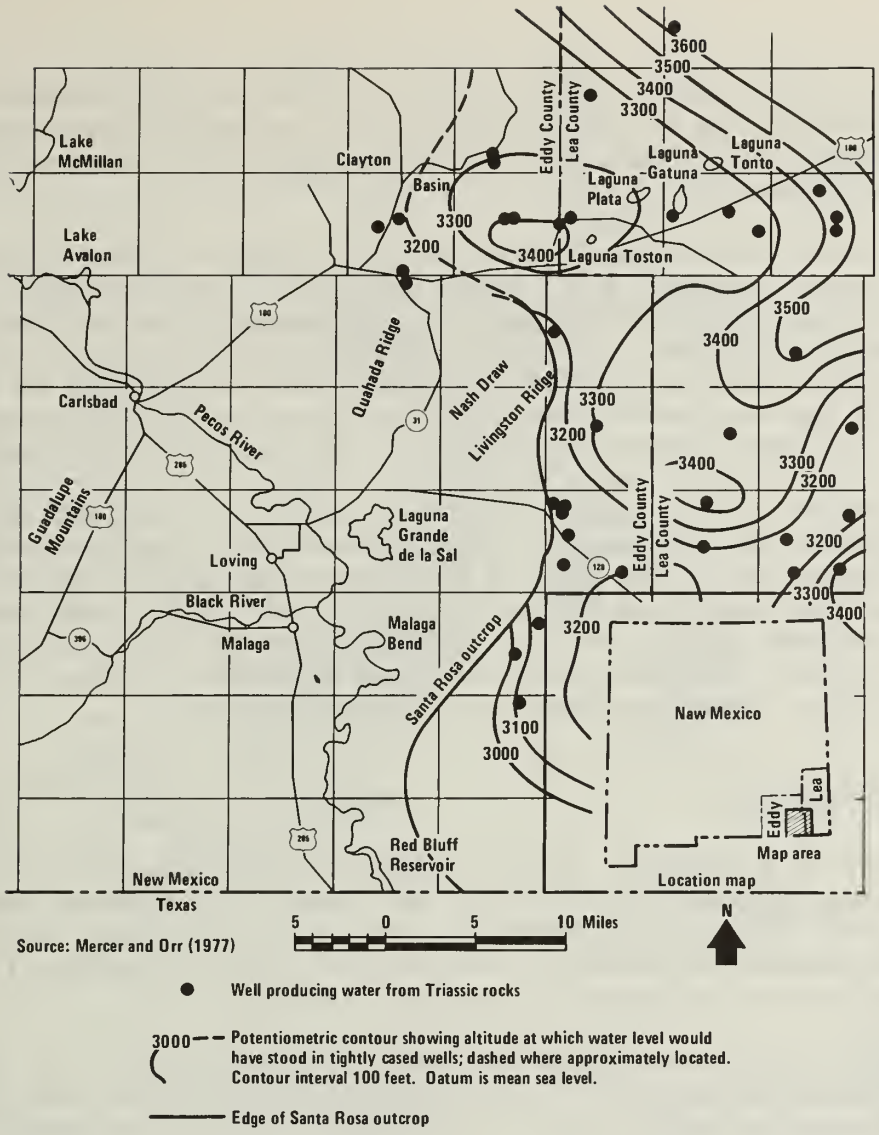


Figure 7-24. Potentiometric surface map of the Santa Rosa Sandstone, 1952 through 1973.

Groundwater flow

Groundwater in porous formations west of the Pecos River flows eastward from the Guadalupe Mountains. The alluvium and shallow aquifers contribute groundwater to the base flow of the Pecos and provide a potable-water source for Carlsbad (Hendrickson and Jones, 1952). Brine solutions under a hydraulic head established presumably by fresher groundwaters of outcrop zones in the Guadalupe Mountains flow northeasterly in the Delaware Mountain Group under the Delaware basin to slowly discharge into the base of the Capitan aquifer.

Groundwater in the Capitan aquifer east of the Pecos River but west of the hydrologic barrier near the Eddy-Lea County line either moves very slowly or is static. The hydrologic barrier formed by a broken or eroded section in the reef isolates the groundwater users in the west from the larger oil-company

withdrawals in the east. There is little or no coupling between wells on opposite sides of the barrier (Hiss, 1975). The oldest water sample from the Capitan aquifer was groundwater west of the hydrologic barrier (Barr, Lambert, and Carter, 1978).

Groundwater in the Capitan aquifer to the east of the Eddy-Lea County line has been heavily pumped for oil-field flooding. These withdrawals have lowered the potentiometric surface and significantly reduced the artesian head in the eastern portions of the reef. Groundwater flows downgradient in the Capitan aquifer east of the Eddy-Lea County line in response to the oil-field withdrawals, and sources of recharge are the brines in the Delaware Mountain Group and the water resources in the various back-reef formations.

Groundwater in the Rustler Formation east of the Pecos River generally flows southerly and southwesterly along formational gradients and discharges into the Pecos River. The Magenta and Culebra Members of the Rustler, which lie beneath the Dewey Lake Red Beds, tend to be more isolated from percolating rainfall and less productive than comparable regions near Nash Draw with no siltstone cover. The Santa Rosa Sandstone and Rustler Formation provide groundwater for livestock watering and potash mining.

Groundwater quality

Analyses of groundwater from the Delaware basin are shown in Table 7-19. Stable-isotope measurements indicate that sampled groundwater from the Santa Rosa, Rustler, and Capitan Formations comes from rainwater. None of the saline groundwaters were found to be original evaporite mother liquors or products of partial evaporation (Lambert, 1978).

There is a shallow-dissolution area in the residuum of the Salado-Rustler contact underlying Nash Draw. Extending from northwest of Nash Draw southwestward beyond the Pecos River, it is about 30 miles long and 2 to 10 miles

Table 7-19. Chemical Analysis of Groundwater in the Delaware Basin[a]

Sample name	Formation sampled	pH	Dissolved-solids concentration (mg/l) Total	Chloride	Sulfate	Sodium	Calcium
Carlsbad Well 7	Capitan	7.2	474	10	72	8	74
Hackberry	Capitan	6.0	192,000	110,800	5,150	68,700	2200
Middleton	Capitan	7.4	33,800	17,050	3,720	10,600	1100
Shell No. 28	Capitan	7.1	11,300	3,900	2,400	2,280	940
James Ranch	Rustler	7.6	3,240	400	1,570	68	590
Duval mine/ collector ring	Rustler	7.4	14,380	6,400	2,500	3,600	1100
H3, Magenta	Rustler	7.4	14,800	5,800	2,600	4,200	760
H3, Culebra	Rustler	7.4	60,000	33,000	5,200	19,000	1500
Duval mine/ seep-BT58	Salado	5.5	395,000	250,000	3,100	46,300	520
ERDA-6	Castile	7.3	321,000	186,100	16,000	112,000	130

[a]Data from Lambert (1978).

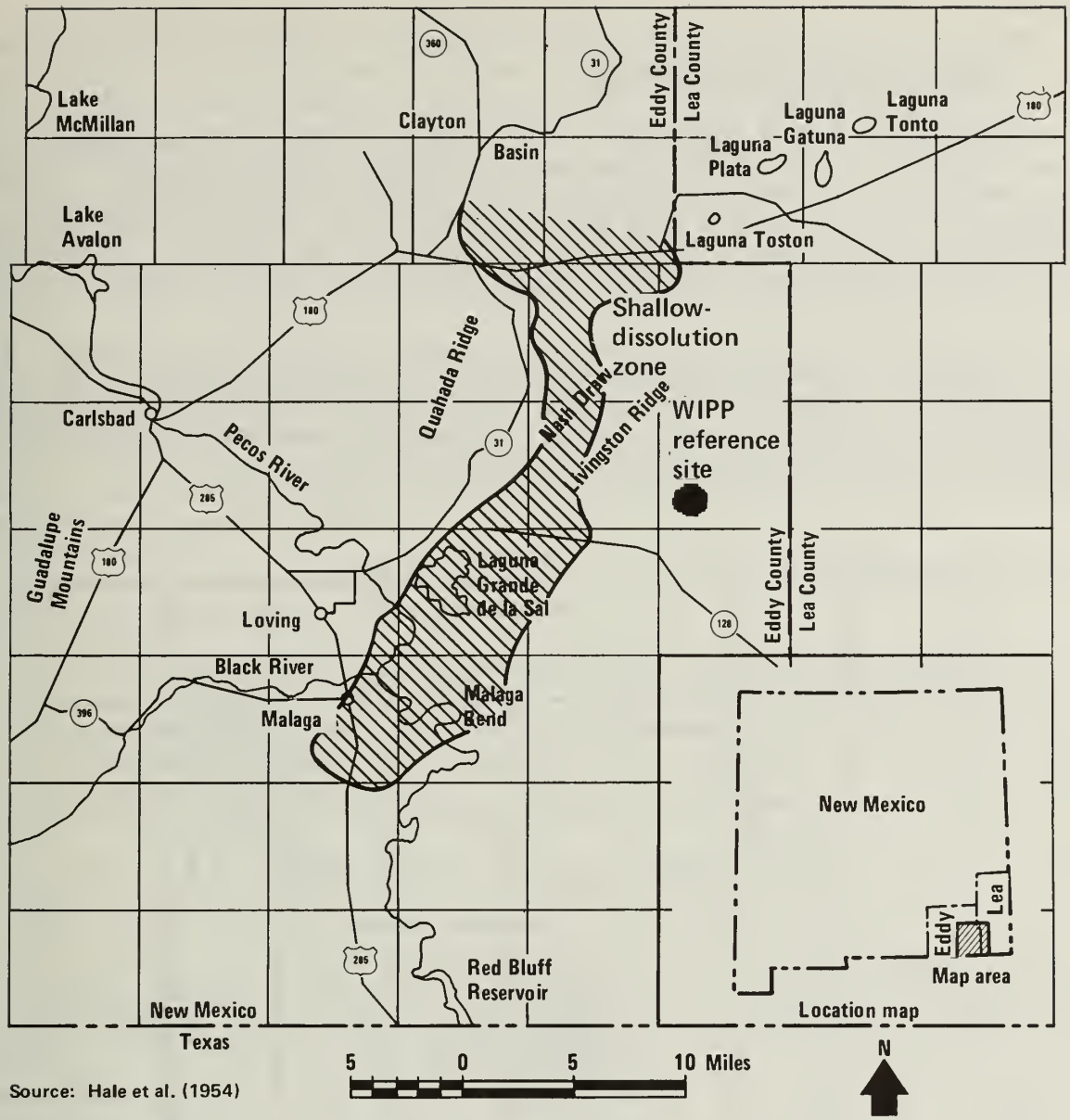


Figure 7-25. Location of the shallow-dissolution zone.

wide (Figure 7-25). Water presumably escapes from the strata above the Salado through fractures and solution zones and moves southward along the upper salt surface to discharge as brine into the Pecos River at Malaga Bend. Recharge is augmented by potash effluent discharged into Nash Draw.

Tests between Malaga Bend and Laguna Grande de la Sal show the Salado-Rustler contact zone which contains brine, to have a transmissivity of 8000 ft^2/day. Assuming (from drill-hole information) an average thickness of 50 feet, a hydraulic gradient of 1.4 ft/mile, and an effective porosity of 20%, the rate of brine movement would be about 0.2 ft/day. Estimates of brine discharge into the Pecos River are 200 gpm (Theis and Sayre, 1942) to about 300 gpm (Hale et al., 1954).

7.3.3 Local Groundwater Hydrology

As of February 1979, hydrologic tests had been made on 12 exploratory holes at the site. Of these, five holes were specifically designed for hydrologic testing: H-1, the H-2 complex (three holes), and H-3 (Figure 7-26). Complexes H-4, H-5, and H-6 have been drilled but not tested. A more detailed description of the continuing hydrologic studies at the site is given in the Geological Characterization Report (Powers et al., 1978, pp. 105ff).

In general, the hydrologic testing program was directed at determining the static head or reservoir pressure, the water-yielding potential of the rock strata, and the chemistry of formation water beneath the site. Data analysis was aimed at evaluating geologic stability and groundwater-transport characteristics. A site geologic column is shown in Figure 7-8.

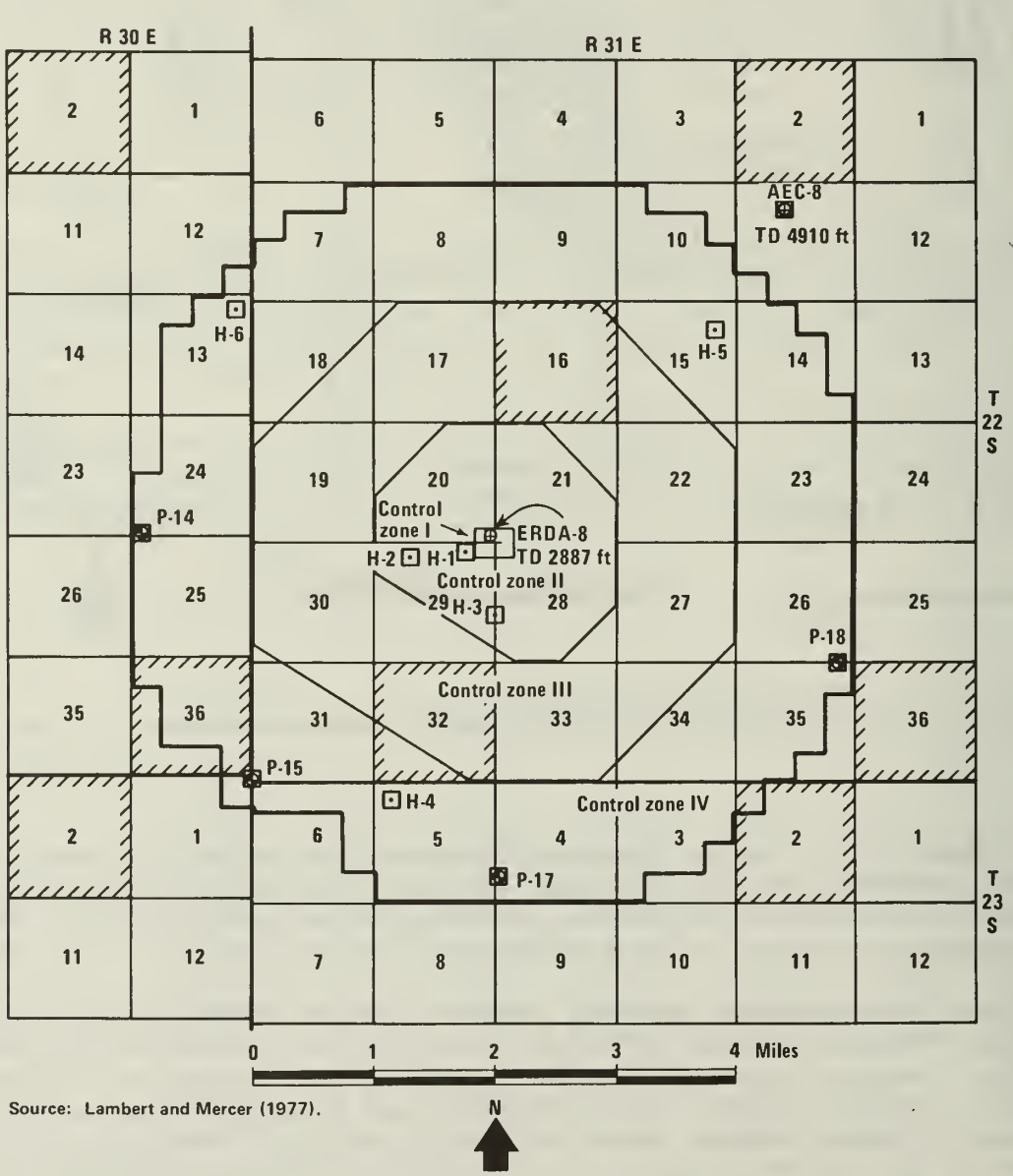


Figure 7-26. Hydrologic test holes.

Drill-hole measurements at the site (Figure 7-26) show little groundwater above the Salado. To date, exploration by the U.S. Geological Survey has concentrated on the fluid-bearing zones of the Rustler Formation and the Rustler-Salado contact (Mercer and Orr, 1978). These zones are the most probable avenue for radionuclide transport through the geosphere to man, and knowledge of their hydraulic characteristics is necessary for estimating potential health hazards. Groundwater in the Rustler Formation and the Rustler-Salado contact is considered a valuable resource when it can be used for livestock (Rustler) or potash refining (Rustler-Salado contact); however, it usually contains total-dissolved-solids concentrations of more than 3000 ppm.

The Bell Canyon Formation of the Delaware Mountain Group yields unsaturated brines that have sufficient "freshwater" head to reach the Rustler Formation but are blocked by the Castile Formation. The hydraulic conductivities of the Castile and the Salado have been measured at the AEC-8 and ERDA-9 exploratory holes. The test results (Tables 7-20 and 7-21) show that the two formations are extremely tight.

Conclusions on the occurrence of fluids in the rock units under the site can be summarized as follows (Mercer and Orr, 1978):

a. Monitoring of fluid-bearing zones in the Rustler shows hydraulic potential to decrease with depth; potential fluid movement would thus be downward in rocks above the salt. However, the large potential differences between fluid-bearing units in the Rustler indicate little or no vertical connection.

Table 7-20. Stratigraphic Summary[a]

Formation top	ERDA-9		AEC-8	
	Depth (ft)	Elevation (ft)	Depth (ft)	Elevation (ft)
Gatuna	27	3388	---	---
Santa Rosa	54	3361	26	3516
Dewey Lake	63	3352	174	3368
Rustler	550	2865	669	2873
Magenta	610	2805	725	2817
Culebra	720	2695	843	2699
Salado	860	2555	994	2548
103 Marker (base)	1050	2365	1170	2372
Vaca Triste (base)	1370	2045	1476	2066
124 Marker (base)	1670	1745	1741	1801
126 Marker (base)	1744	1671	1822	1720
136 Marker (base)	2058	1357	2128	1414
139 Marker (base)	2180	1235	2248	1294
Cowden (top)	2540	875	2540	1002
Cowden (bottom)	2562	853	2563	979
Castile	2836	579	2982	560
Delaware	---	---	4315	-773
Total	2887	528	4910	-1368

[a]AEC-8, drilled to 3028 feet on May 10, 1974, was reentered and deepened to 4910 feet during July and early August 1976.

b. The distribution of head in the Culebra dolomite indicates fluid movement to the southeast across the site. Gradients are 7 to 120 ft/mile and are lowest where hydraulic conductivity is greatest.

c. The distribution of head in the Magenta dolomite has been determined in only three holes and indicates fluid movement to the southwest. The hydraulic gradient is 50 ft/mile.

d. Fluids in the Culebra and Magenta apparently move primarily along fracture systems, through low-yielding fractured rocks whose effective porosities and hydraulic conductivities are hard to obtain.

e. Very low yields of brines were found along the Rustler-Salado contact.

f. Evaluation of tests on Bell Canyon sands is incomplete, but preliminary results at AEC-8 show the potentiometric surface, corrected to freshwater density, to be higher than similarly corrected levels of fluid zones in the Rustler.

7.3.4 Dissolution of Salts in the Permian Evaporites

Solution and subsidence features are common in southeastern New Mexico. Depressions near the site range from features a few meters in diameter to features the size of Laguna Grande de la Sal (Salt Lake), 11 miles to the west-southwest of the site, and Laguna Plata and Laguna Gatuna, 14 miles to the north. Not all depressions were formed by solution and collapse. Laguna Plata and Laguna Gatuna, for example, were formed as blowouts, and others resulted from the solution of caliche.

It is estimated that up to 50% of the original salt of the Delaware basin evaporites has been removed (Anderson, 1978), either by surface erosion or by groundwater. These processes have been intermittent for more than 100 million years (Bachman, 1974). Salt has been removed by water percolating downward (mainly from precipitation falling on the ground above the salt), leaving behind insoluble material referred to as a leached zone (Vine, 1963). The shallow dissolution beneath Nash Draw is such a zone and is apparently the migration route for the leached salts that discharge into the Pecos River.

Table 7-21. Calculated Hydraulic Conductivity from Drill-Stem Tests in ERDA-9[a]

Formation	Test depth (ft)	Hydraulic conductivity (ft/day)
Salado	1440-1496	
Salado	2026-2106	15.8×10^{-6}
Salado	2524-2630	5.25×10^{-6}
Salado/Castile	2635-2886	15.8×10^{-6}

[a]Derived from Lambert and Mercer (1977).

Salt has also been dissolved from within the evaporites, generally resulting in the collapse and lowering of the overlying strata. Anderson (1978) recognized the insoluble residue as a blanket-dissolution breccia that occurs west of the present salt edge. Deep-dissolution phenomena in the evaporites may also have developed more localized collapse features, recognized around the margin of the basin and within the basin (Maley and Huffington, 1953). Their origin is more problematical than that of surface dissolution, and the rates of dissolution are more difficult to assess. The water that dissolved the salt in other areas of the region is believed to have come from aquifers beneath the salt beds, through fracture systems in the rocks (Anderson, 1978).

Shallow dissolution

The depth of shallow dissolution in the evaporites (base of leached zone) is very irregular but usually less than 300 feet near the proposed site. It is developed in the western part of the Delaware basin, where the evaporites are exposed or near the surface. In Nash Draw, where the Rustler Formation is exposed, leaching extends into the Salado. East of Nash Draw, down-dip into the Delaware basin, the evaporite formations become progressively deeper, and the present-day top of the salt is found progressively higher in the stratigraphic section. The top of salt is at the top of the Salado Formation about 2 miles west of the site center and becomes progressively higher in the Rustler Formation across the site (Figure 7-27).

Jones (1972) reported the solution front in the Salado Formation to be between 2 and 3 miles west of the site center. Bachman (1974) attributed a thinning of the upper member of the Salado west and north of the site to both the original deposition and subrosion during the middle and late Cenozoic. West of the front there is almost a fourfold reduction in thickness, to as little as 150 to 170 feet in some places. This is the residue of a 500-foot section after leaching by circulating groundwater.

As dissolution progresses, voids develop and the residue is weakened until it is no longer able to support the overburden. Slumping of the residue and collapse of the roof can extend to the ground surface, resulting in a topographic sink. The resulting distinctive pitted terrain, called "karst," has poorly developed surface drainage and is extensive in southeastern New Mexico.

Another large depression cited by Bachman is San Simon Swale, 22 miles east of the site. Shallow dissolution is a factor in its development, which apparently still continues. The last recorded collapse occurred about 40 years ago (Nicholson and Clebsch, 1961). Many sinks along the Pecos River Valley have collapsed in historic times (Bachman, 1974). As recently as 1973, a small collapse sink formed at Lake Arthur, about 50 miles north of Carlsbad.

Deep dissolution

Large deep-dissolution features filled with Cenozoic sediments overlying the inner margin of the Capitan reef were recognized by some of the first geologists working in the Delaware basin (Maley and Huffington, 1953). The source of water was attributed to the Capitan aquifer.

The most prominent small-scale (less than 1 mile across) dissolution features near the Delaware basin have been described by Vine (1960) as "domal karst features." The subsurface projection of one dome (dome C), found at the

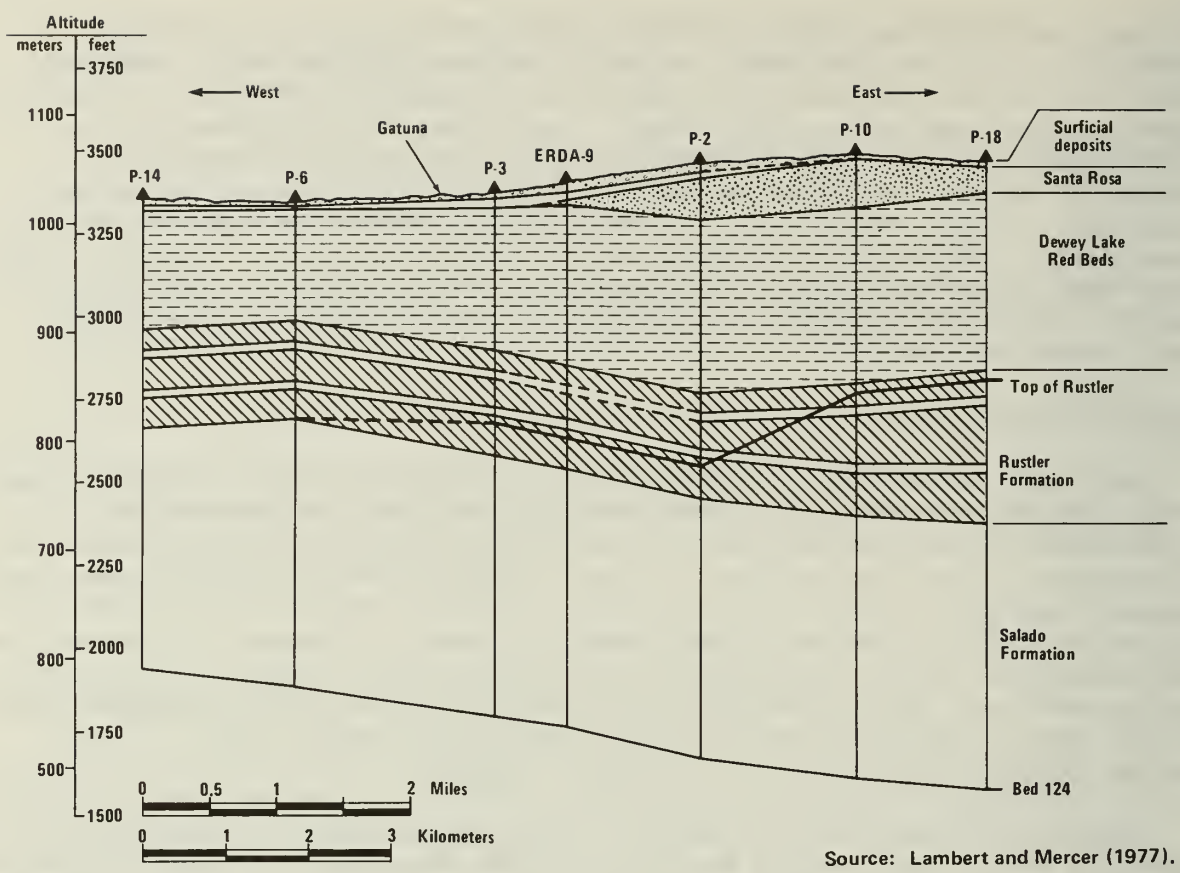


Figure 7-27. Geologic section through the Los Medanos area.

level of the McNutt Potash Zone by the Mississippi Chemical Corporation, was a chimney in the Salado filled with clay-cemented brecciated rock belonging to higher strata. There are similar erosion-breached domes in the vicinity of Nash Draw. Their subsurface expression is unknown. A chimney containing cemented rubble (incorrectly termed a "breccia pipe") was encountered in exploratory drilling near the Weaver Mine, but it was not associated with a breached dome at the surface. Recent geophysical surveys have shown that many of these hills, including the "Weaver Pipe" and Vine's dome C, are associated with resistivity lows.

Anderson (1978) believes that deep dissolution is an ongoing process. The site is in an area of the Delaware basin that is relatively free of regional deep dissolution, but localized features are present in the vicinity. Nevertheless, extensive investigations at the proposed site, including exploratory holes ERDA-10, ERDA-9, and AEC-8, show no continuing deep dissolution (Powers et al., 1978, pp. 6-40ff).

Rates of dissolution

Dissolution is an active process and can be expected to continue. To evaluate the potential hazard to the site of continued dissolution in nearby places such as Nash Draw, the rates of dissolution are estimated. Nash Draw appears to have subsided between the Livingston and Quahada Ridges as much as

180 feet since Mescalero time. At one place its surface is 180 feet below the projected altitude of the Mescalero caliche. However, the interval between the top of the Salado Formation and the top of marker bed 124 at the same location is 420 feet, or 330 feet less than at the Livingston Ridge, where relatively little of the Salado salt has been removed. It is concluded that about 150 feet of the Salado salt was removed before Mescalero time and about 180 feet since. With this in mind, Bachman (1974) analyzed the dissolution in Nash Draw as occurring since the development of the Mescalero caliche, 600,000 years ago, and found that the average vertical dissolution was about 0.33 foot per 1000 years.

Clearly, this rate is not a constant for the region. At least two other factors must be considered, but no geologic information is available for their evaluation:

a. Dissolution and subsidence rates probably have not been constant in Nash Draw during the past 600,000 years. Much of the subsidence may have occurred during periods of high rainfall in the late Pleistocene (Wisconsin time).

b. The subsidence in Nash Draw, whenever it occurred in the Pleistocene, is not an average rate for the region. In the area of "the Divide" between the Antelope and Livingston Ridges, the Mescalero caliche is relatively undisturbed, suggesting no dissolution since Mescalero time.

An alternative approach was used by F. A. Swenson (Bachman and Johnson, 1973), who estimated the maximum amount of salt dissolved and discharged by springs and streams along the east flank of the basin to be 955 tons per square mile each year. This gives a present vertical dissolution rate of about 0.5 foot of salt in 1000 years.

The estimated lateral shallow dissolution in the western part of the Delaware basin is about 6 to 8 miles per million years (Bachman and Johnson, 1973), based on the assumption that the Salado Formation extended to the Capitan reef escarpment on the western edge of the basin at the end of Ogallala time. It is now recognized that the dissolution of this salt could have occurred at earlier times in the past, and the average rate of salt removal by shallow dissolution is believed to be much slower than those estimates.

The rate of deep dissolution is difficult to assess, and Anderson (1978) does not believe that estimates can be made with any degree of confidence from the available data. In any case, deep dissolution does not occur near the site.

7.4 ARCHAEOLOGY

Little archaeological research has been done in southeastern New Mexico. Interest has instead tended to focus on areas to the north and west, partly because of the more spectacular ruins there--such as Chaco Canyon and Mesa Verde--and partly because of the possibility of relating these ruins to the present Pueblo Indians. These northern areas were felt to be the major cultural centers, whereas southeastern new Mexico has been regarded as a less fruitful area for investigation than areas to the north and west. More recently, however, the marginal nature of the southeastern environment has been recognized as offering opportunities for studies on the relationship between environment and culture.

Studies by Mera (1943), Lehmer (1948), and Jelinek (1967) are the three basic sources of information on the archaeology of southeastern New Mexico. Lehmer synthesized the knowledge of the archaeology of the area and incorporated Mera's data to define what he called the Jornada branch of Mogollon culture. This did not include the more easterly portions of southern New Mexico or the area of the WIPP reference site but did form the basis for the classification of sites in those portions of the State. The time scale of this synthesis was from the early Christian era to 1400 A.D. Jelinek conducted a survey of the Pecos Valley north of Roswell. The earliest phase he identified, his "Early 18 Mile" (800-900 A.D.), was generally similar to late Archaic. The area appears to have been abandoned for some time after the mid-14th century. The studies of Lehmer and Jelinek and later field observations in Lea and Eddy Counties led to the extension of the boundaries of Lehmer's Jornada Mogollon to include the rest of southeastern New Mexico.

Various groups of expert amateurs, especially the Lea County Archaeological Society, have been active in excavation, survey, and publication of the archaeological values of southeastern New Mexico. Contract archaeological firms have also been active in the Carlsbad Potash District immediately west and north of the study area for the reference repository.

A Bureau of Land Management study (BLM, 1975) has estimated the archaeological site density in the potash areas, using data gathered by Eastern New Mexico University (ENMU) on a survey to the north and projections made by Schaafsma (1975) from similar areas elsewhere in New Mexico. It concluded that the "site densities within the potash basin may be expected to range between 12 and 15 sites per square mile. The majority of these sites will be located in dunes, on cliffs, in close proximity to playas, or a combination of these." In its report, the BLM did not indicate what constituted a site.

Prehistoric dwellings are exceedingly rare in southeastern New Mexico. The nearest known dwellings to the reference site are at Maroon Cliffs, 11.5 miles northwest. The presence of pit houses has not been confirmed there, but year-round occupation is suggested by a deep midden recently excavated by ENMU. The Lea County Archaeological Society reported pit houses at Laguna Plata, 15 miles north, though J. L. Haskell (ENMU, personal communication) questions its conclusions. The nearest confirmed pit houses are at the Marchant site (southwest of Hobbs and about 18 miles east of the site), excavated by the Lea County Archaeological Society in the 1960s (Leslie, 1965).

In the summer of 1976, ENMU surveyed the central 4 square miles of the site, including all of control zones I and II (Figure 8-2). They found 64 isolated artifact sites and 33 archaeological sites. The latter were taken to be localities that were used and occupied by prehistoric man. One such site, with a metate, is shown in Figure 7-28.

The number of sites corresponds to an average density of eight per square mile, significantly fewer than the Bureau of Land Management had inferred from earlier surveys. ENMU classified the 33 sites according to a scale defined by the School of American Research: Task Locus, Special Activity Zone, Limited Base, Home Base, Central Base, and Occupation Zone. By this scale, twenty-seven of the sites (including the one shown in Figure 7-28) are Task Locuses and the remaining six are Special Activity Zones. No pit houses, permanent structures, or other indications of heavy use were found (a later exception is found below).

The main conclusions of ENMU were as follows (Nielsen, 1976):

> Cultural resources are remarkably uniform across the area. Groundstone consists of wedge-shaped manos, and oval-shaped metates.... Although few in number, potsherds belong to the El Paso Brown, Jornada Brown, and Chupadero Black-on-White types, which date between A.D. 900-1300. These resources are tied to the Jornada Branch of the Mogollon. Of the seven projectile points found, one was from the Archaic period (4000 B.C. to A.D. 500). The others were probably of Jornada Mogollon authorship....Hearths were often noted, with their presence being indicated either by a dark stain in the soil, or by a scatter of burned caliche or sandstone.
>
> It is believed that the area was occupied seasonally by hunting/gathering bands. The prime resources are acorns, mesquite beans, rabbit, and deer. Owing to the relatively large number of groundstone fragments, it seems likely that these acorns and mesquite beans were probably primary resources of these people.

The site investigation has so far (March 1979) required building about 30 miles of new road, drilling 45 holes, installing a meteorological tower, running 79 miles of off-road seismic lines, and making about 9000 off-road resistivity measurements. Much of this work was outside the 4 square miles surveyed by ENMU and required archaeological clearance. In the process more sites have been discovered. The most interesting new find was a room block just outside the intensely surveyed central area. This was in the shape of a reversed "L," approximately 23 by 26 feet. The foundation only remains; it is not of dressed stone but adobe or jacal. Nearby are a series of rectangular arrays of caliche blocks. Superficially this find seems to be of the early to middle Jornada Mogollon period and to be a small dwelling or dwelling complex.

The rights-of-way for the WIPP reference repository have not been surveyed archaeologically. These surveys must await the layout of roads, electrical-power line, and railroad.

Figure 7-28. Overview of the site looking toward the east (top) and oval basin metate (bottom).

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8 The Reference Repository and Its Operation

8.1 CURRENT AND PROPOSED LAND USE

8.1.1 Location and Description

The WIPP reference site is in Eddy County in southeastern New Mexico, 25 miles east of Carlsbad (Figure 8-1). The land area committed to the project will be approximately 6 miles in diameter. It will contain 18,960 acres (29.6 square miles) in four townships: T 22 S, R 31 E; T 23 S, R 31 E; T 22 S, R 30 E; and T 23 S, R 30 E. The actual area under DOE control will not be a true circle because of the necessity of squaring up the boundaries for legal description (Figure 8-2).

8.1.2 Current Land Use Within a 30-Mile Radius from the Site

Figures 8-3 and 8-4 show land status and use within a radius of 30 miles from the WIPP reference site. From these maps it is apparent that there is very little private land in the area. Most of the land is owned by the Federal Government or the State of New Mexico.

The dominant use of the land around the site is grazing; the average number of animals per section is approximately six to nine (Appendix H). There are numerous active oil and gas wells. The only agricultural land within a 30-mile radius is irrigated farmland along the Pecos River, near the municipalities of Carlsbad and Loving; very little, if any, dry-land farming takes place within the area.

At present, land use within a radius of 10 miles from the site consists of potash-mining operations, active oil and gas wells, and grazing. With or without the reference repository, this pattern is expected to change little in the future.

8.1.3 Control Zones

The four control zones at the site, shown in Figure 8-2, will be under the full control of the DOE. The DOE'S intent is to exercise successively fewer restraints on surface and underground use at increasing distances from the center of the site.

Control zone I, covering about 50 acres in Sections 20, 21, 28, and 29 of T 22 S, R 31 E, will contain most of the surface facilities. It will be surrounded by a security fence, with provisions for visual surveillance by closed-circuit television and possibly by electronic intrusion detectors. The plant will be open to public visits and tours; as a safety precaution, however, access must be controlled to insure that the number and location of persons in control zone I are known at all times.

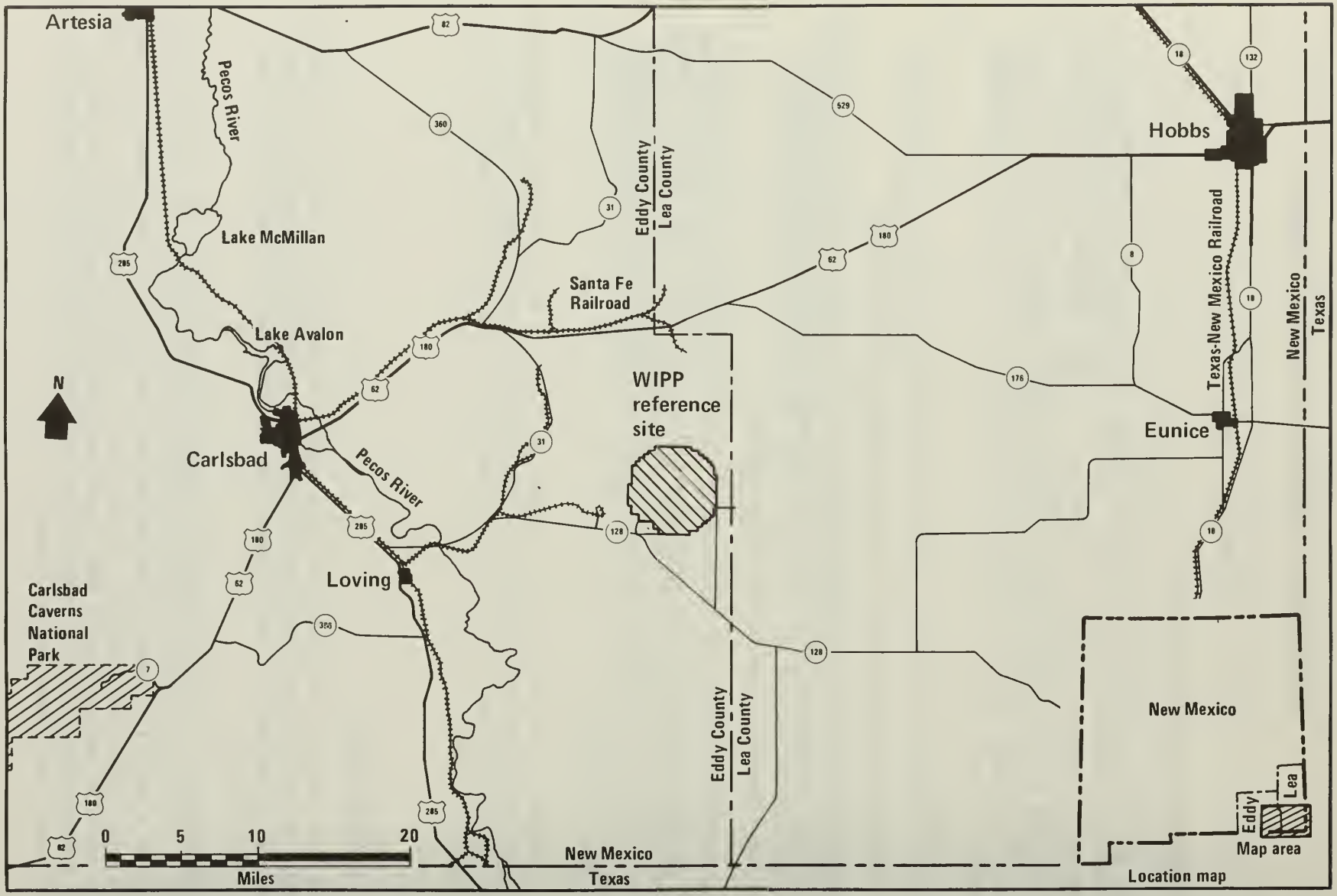


Figure 8-1. General location of the WIPP reference site.

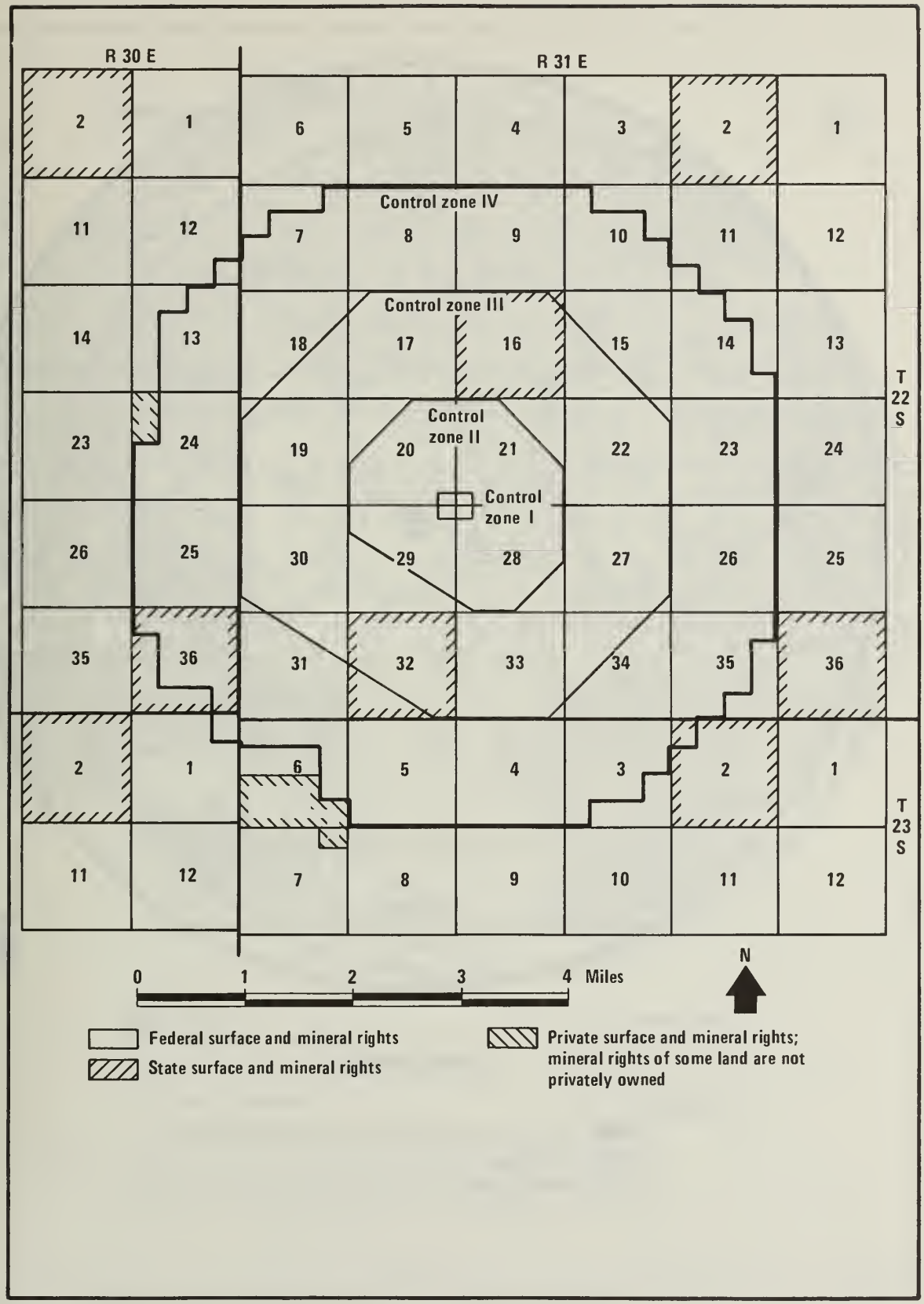


Figure 8-2. The WIPP reference site.

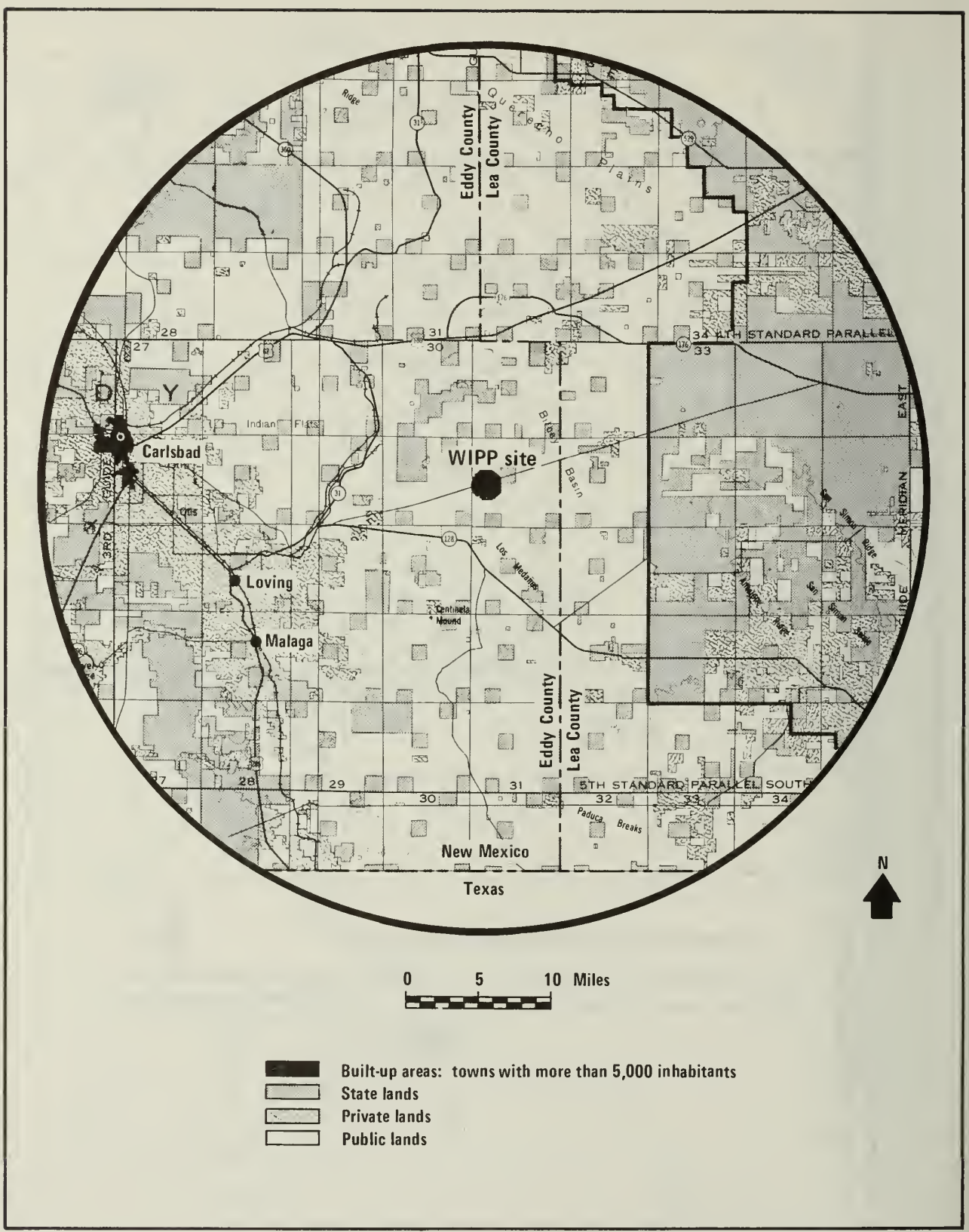
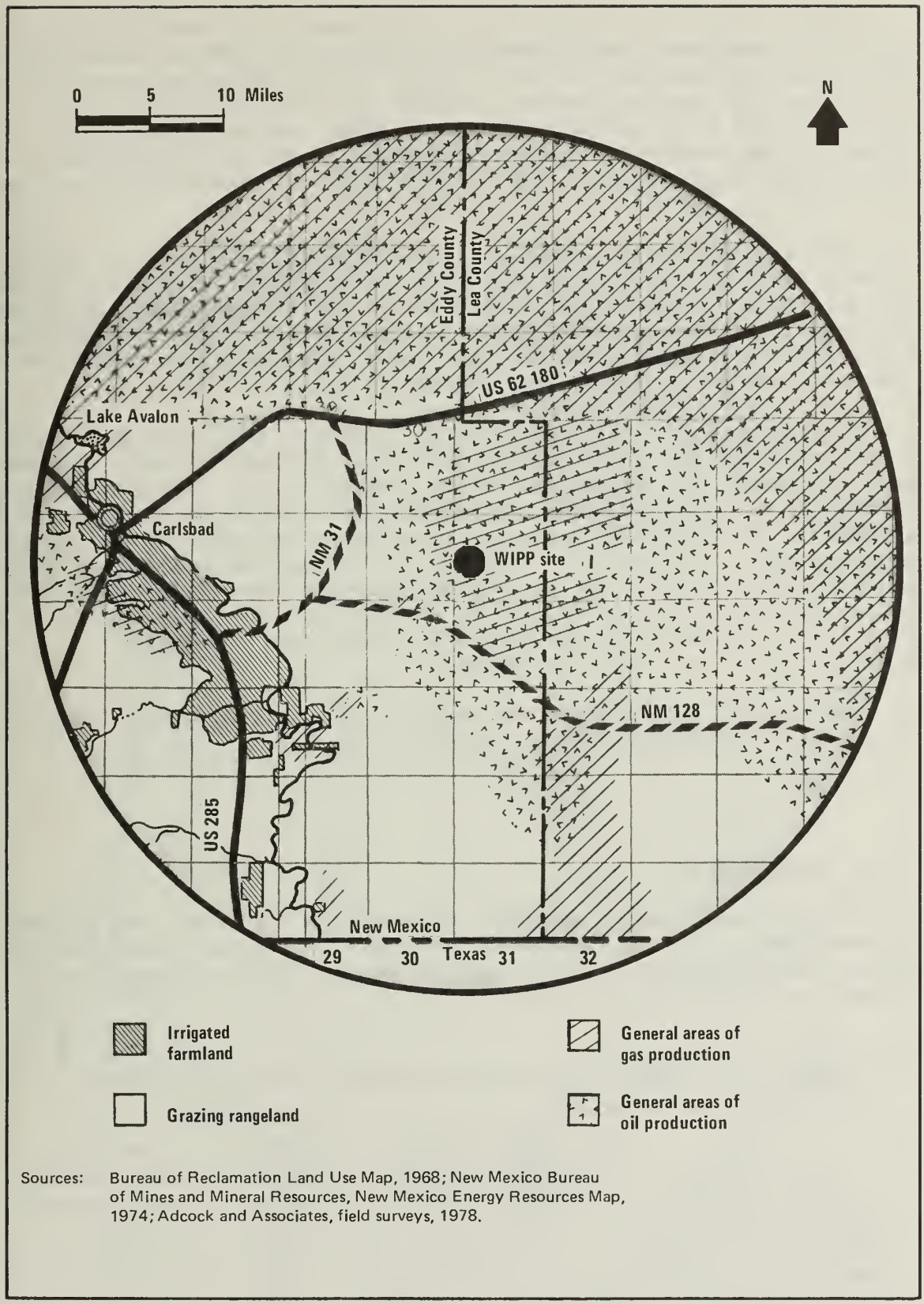


Figure 8-3. Land status within a 30-mile radius of the WIPP reference site.



Sources: Bureau of Reclamation Land Use Map, 1968; New Mexico Bureau of Mines and Mineral Resources, New Mexico Energy Resources Map, 1974; Adcock and Associates, field surveys, 1978.

Figure 8-4. Land use within a 30-mile radius of the WIPP reference site.

Control zone II, an area of about 1800 acres, will overlie the maximum extent of underground development; all radioactive waste will be emplaced underground beneath control zone II. It will not be fenced except for two 5-acre and two 20-acre areas set aside as long-term biological study plots. Livestock will be permitted in this zone under controls like those of the Bureau of Land Management and State agencies on the surrounding land. Only drilling and mining carried out by the DOE will be permitted within this control zone.

Control zone III, surrounding control zone II, will have an outside diameter of 4 miles and an area of about 6200 acres. It will not be fenced, and grazing will be permitted. With permission from the DOE, shallow wells may be drilled for stock water, but no other drilling or mining will be permitted unless evaluations now in progress show that such activities can be conducted without damage to the repository.

Control zone IV, surrounding control zone III, will have an outside diameter of 6 miles and an area of about 11,000 acres. Grazing and shallow wells for water will be permitted. Continuous or drill-and-blast mining for potash may be permitted under DOE restrictions, but no solution mining will be permitted. Existing producing oil or gas holes in this zone will be permitted to continue through their useful lives; to protect the repository, they will be sealed as prescribed by the DOE when they are abandoned. New wells for oil and gas production may be drilled in conformance with DOE standards to facilitate eventual plugging; recovery methods like flooding or hydrofracturing will not be permitted.

The DOE will not exercise any control over the land outside control zone IV and will not impose any restrictions on its use.

8.1.4 Rights-of-Way

Rights-of-way must be acquired for access to the site. The proposed rights-of-way, shown in Figure 8-5, and the off-site land areas covered by these rights-of-way (Table 8-1) will be surveyed for the presence of archaeological or historic sites.

Table 8-1. Rights-of-Way for the WIPP Reference Repository

Right-of-way	Length (miles) Total	Length (miles) Off-site	Width (feet)	Off-site area (acres)
Road to north	13	10	200	245
Road to south	4	1	200	25
Railroad	6	3	100	35
Electricity	10	7	75	65
Water (extension)	18	18	100	220
Total				590

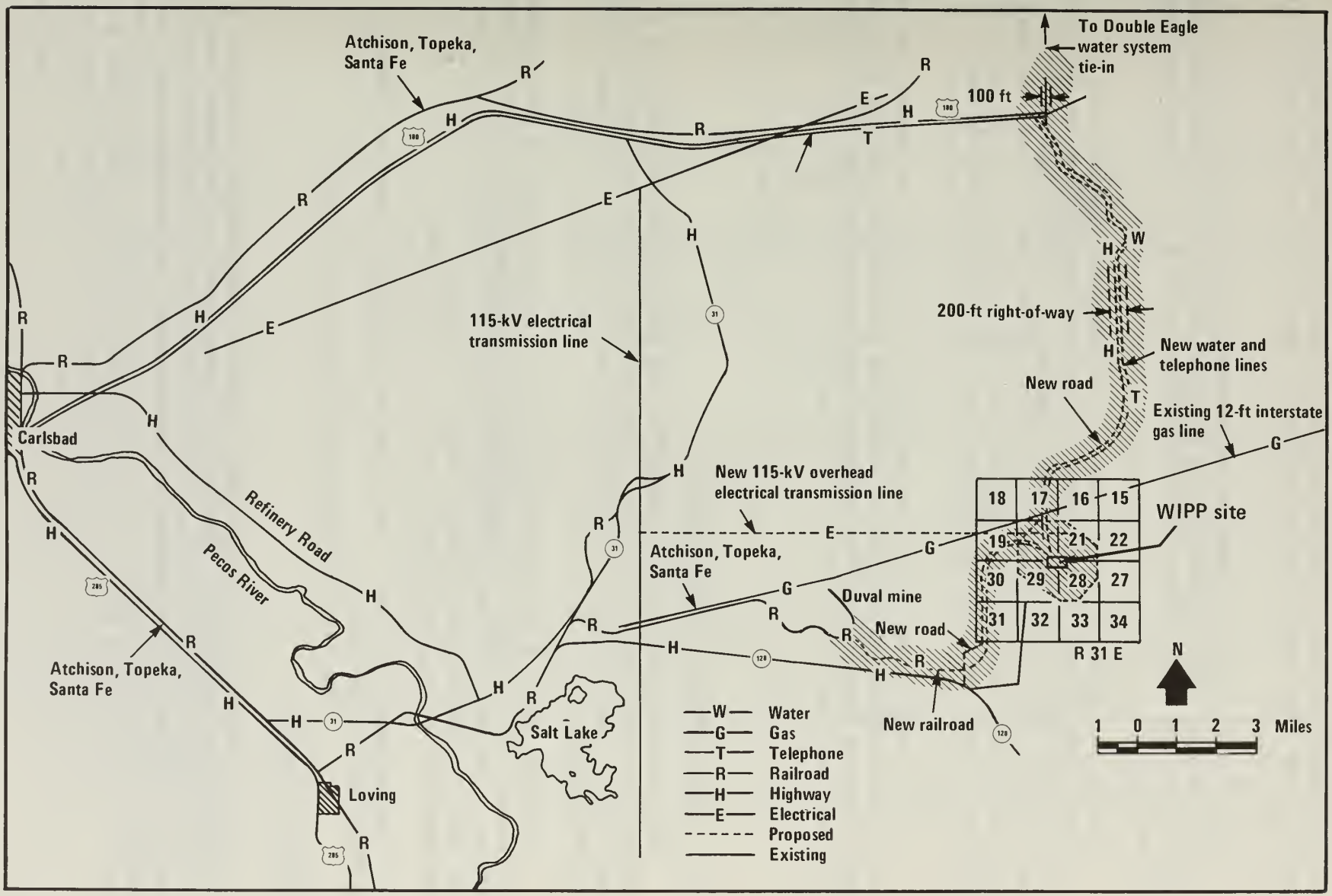


Figure 8-5. Rights-of-way for the WIPP reference repository.

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Present access to the area from New Mexico highway 128 is provided by caliche-surfaced roads built during exploration for oil and gas or for potash, some ranch roads, and extensions of these roads to site-exploration drill holes.

Eventually, access to the area will be from the north and south by new paved highways. Rail access will be provided by extending a railspur that now reaches the Duval Potash Company's Nash Draw mine to the west-southwest of the site.

Electrical power will be brought to the site from the west over a separate right-of-way. A telephone line will be brought from the north on the right-of-way for the new highway. Water will be purchased from the Double Eagle Water System owned by the City of Carlsbad. It will be carried over an 18-mile right-of-way that reaches from a tie-in point on the existing system; it then will move to the north road into the site on the road right-of-way.

After construction is finished on the rights-of-way for electricity and water, those areas, except for an unimproved maintenance track in each, will be allowed to revegetate. The rights-of-way for the road and the railroad will be long-term withdrawals from the natural productivity of the land.

8.1.5 Land Ownership and Leaseholds

All the land that will be needed for the WIPP reference repository is Federal or State land (Figure 8-6). The withdrawal area consists of 17,200 acres (26.9 square miles) of Federal land and 1760 acres (2.75 square miles) of State land.

Although there is no private land inside the boundaries of the proposed withdrawal area, there are two parcels of private land immediately outside the site: 80 acres in the northwest corner of Section 24 (T 22 S, R 30 E) and 40 acres in the extreme southeast corner of Section 6 (T 23 S, R 31 E). The headquarters of the James Ranch is on the latter 40 acres.

The proposed withdrawal area is encumbered by the long-term leases summarized in Table 8-2.

Grazing rights

All of the land in the withdrawal area has been leased for grazing. There are two leaseholders: William and Kenneth Smith of Carlsbad, New Mexico, own the Crawford Ranch, which has lease rights to 6680 acres in the northern portion of the proposed withdrawal area. T. T. Sanders, Jr., of Roswell, New Mexico, owner of the James Ranch, has lease rights to 12,280 acres in the southern portion of the proposed withdrawal area (Figure 8-6).

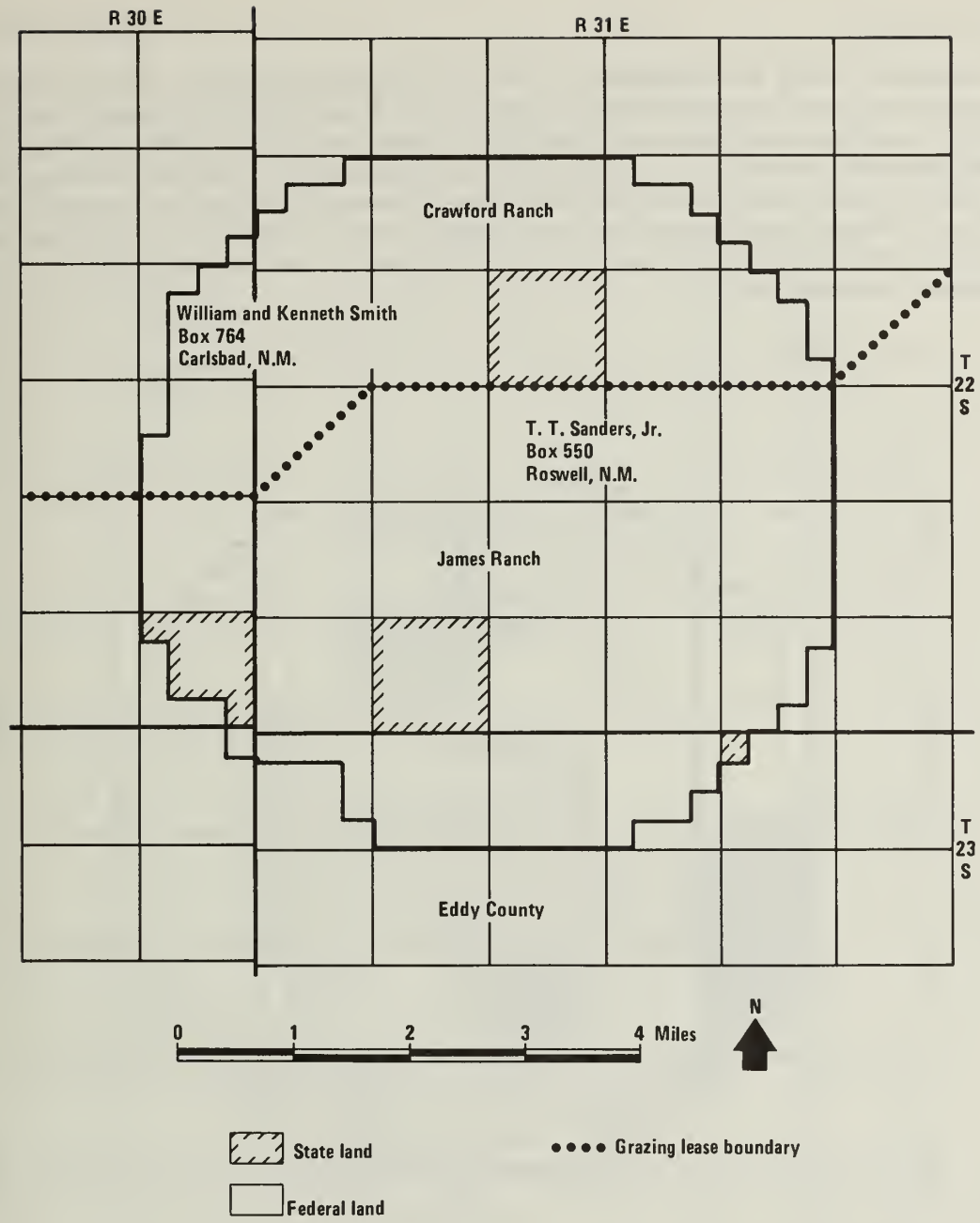

Figure 8-6. Grazing leases within the WIPP reference site.

As part of the development of these grazing lease rights, the Crawford Ranch has a stock well in Section 15 (T 22 S, R 31 E). There are no other water wells at the reference site, although there are a number nearby, especially near the headquarters of the James Ranch outside the southwest border of the site.

According to Bureau of Land Management records, a grazing density of nine cattle per section (70 acres per head of cattle) is permitted on this leased land.

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Potash leases

Less than half the land within the withdrawal area has been leased or has applications pending for potash exploration. As shown in Figure 8-7 and Table 8-2, 4800 acres are now leased by four companies, three of which are already operating mines in the Carlsbad Potash Area. Table 8-2 also shows how much of the inner three control zones is under lease; no potash mining will be permitted within these inner zones for a number of years and perhaps forever. The amount of potash mineralization in the withdrawal area is discussed in Section 7.2.

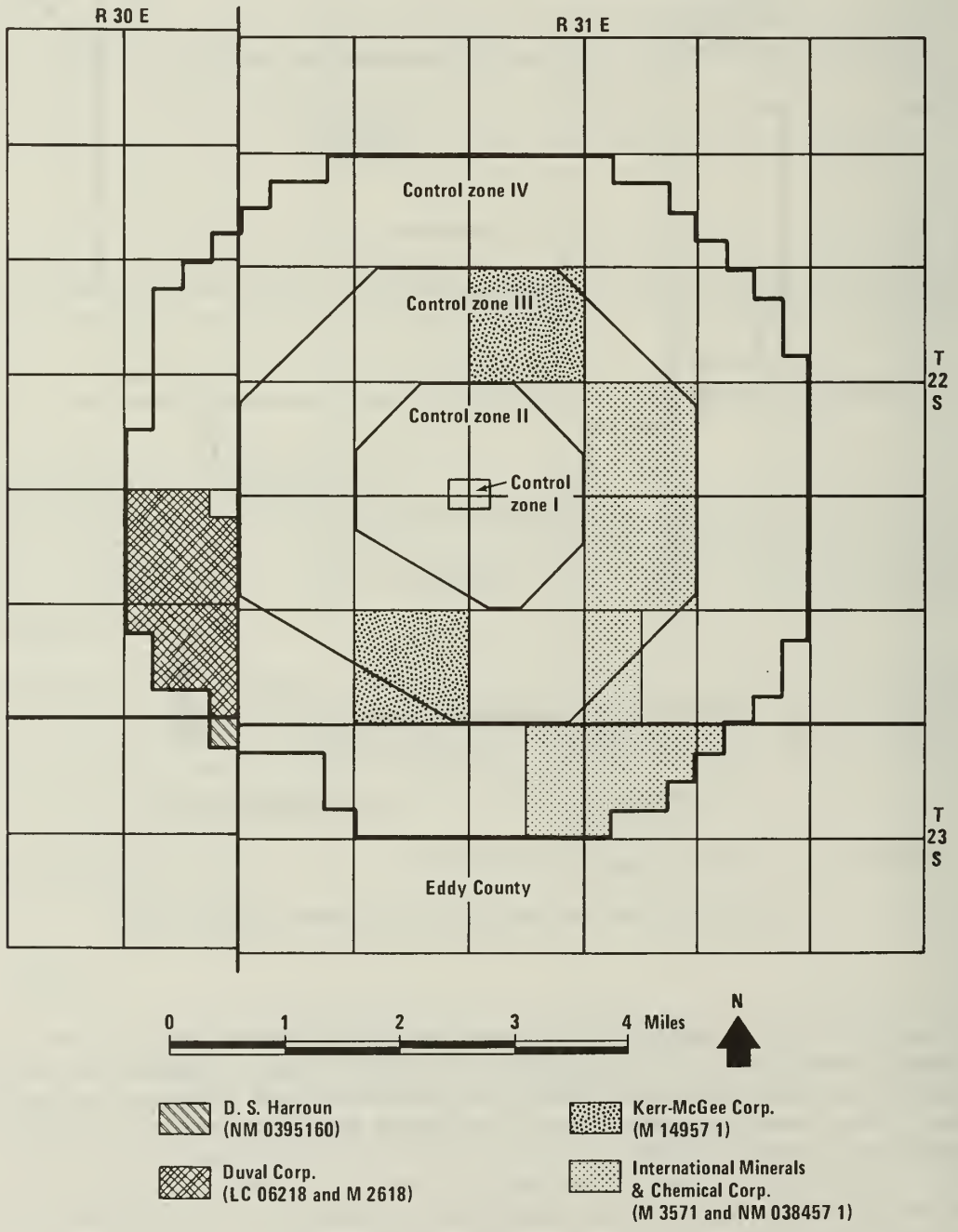

Figure 8-7. Potash leases within the WIPP reference site.

Oil and gas leases

In March 1979, about 6600 acres of the withdrawal area were leased for oil and gas exploration (Figure 8-8 and Table 8-2) by ten companies. Since the beginning of exploratory studies at the site the DOE has acquired oil and gas leases on an additional 7100 acres inside the area. These acquisitions have been necessary to keep the salt beds intact; exploratory drill holes might penetrate the volume of salt that the repository will occupy.

Figure 8-8 shows the four abandoned oil and gas exploration holes within the withdrawal area; all are in control zone IV.

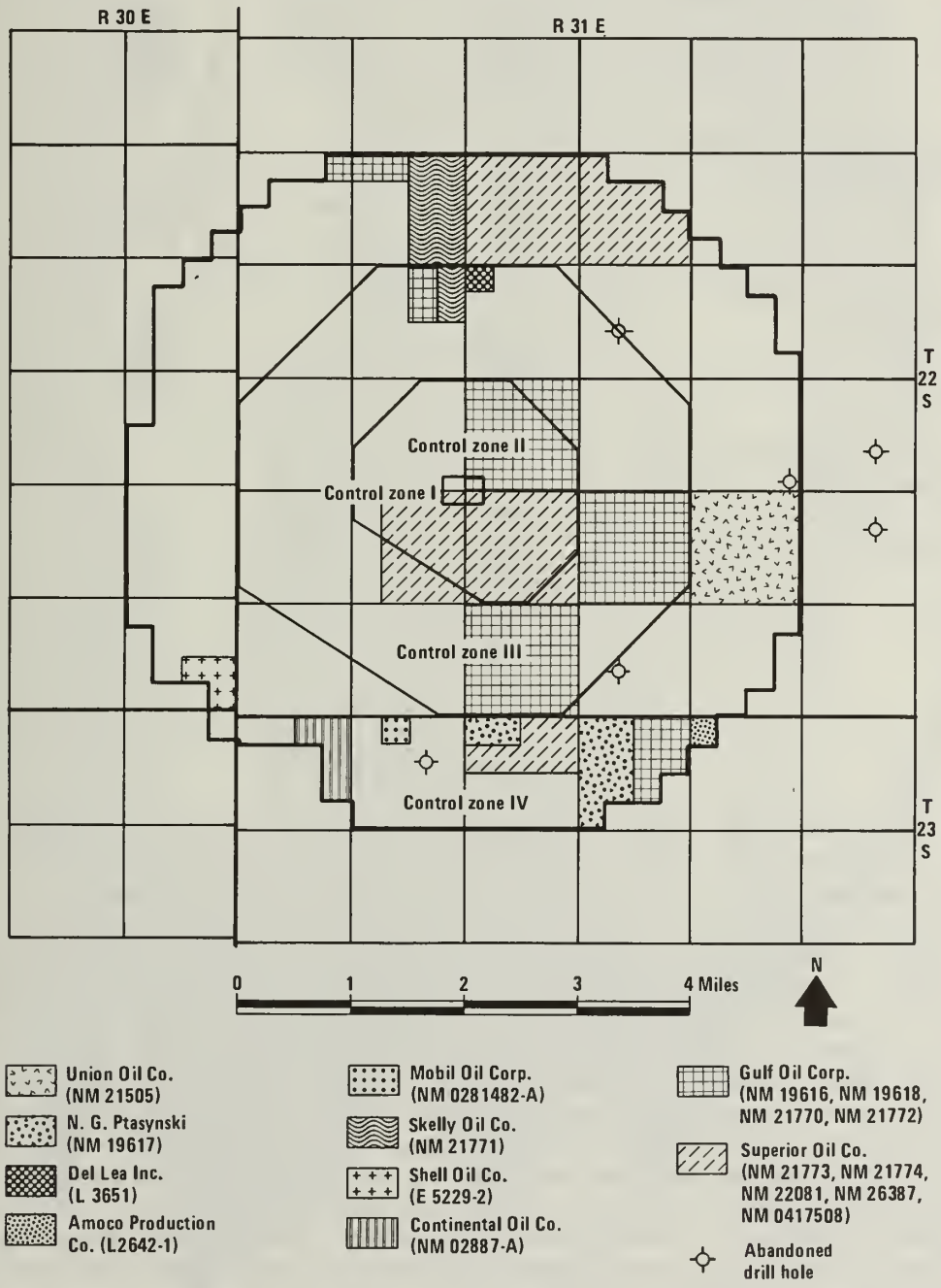

Figure 8-8. Oil and gas leases within the WIPP reference site.

Table 8-2. Summary of Leases at the Site in March 1979

Land status	Whole area Acres	Whole area Percent	Excluding zone IV Acres	Excluding zone IV Percent
Total area involved				
Federal land	17,200		7063	
State land	1,760		1076	
Total	18,960		8139	
Subject to grazing leases				
Federal land	17,200	100	7063	100
State land	1,760	100	1076	100
Total	18,960	100	8139	100
Subject to potash leases				
Federal land	3,040	17.7	1459	20.7
State land	1,760	100	1076	100
Total	4,800	25.3	2535	31.1
Subject to oil and gas leases				
Federal land	6,400	37.2	3186	45.1
State land	200	11.4	40	3.7
Total	6,600	34.8	3226	39.6
Subject to both potash and oil and gas leases				
Federal land	1,280	7.4	640	9.1
State land	200	11.4	40	3.7
Total	1,480	7.8	680	8.3

8.2 GENERAL DESCRIPTION

The WIPP reference repository (Figure 8-9) is designed to receive, inspect, overpack when necessary, and permanently dispose of radioactive wastes in bedded salt. It is a repository for defense TRU waste, a demonstration of the disposal of spent power-reactor fuel, and an experimental facility for in-situ tests of techniques proposed for the disposal of high-level wastes. The plant consists of both surface and underground facilities, including a waste-handling building for receiving and preparing radioactive waste for transfer underground, an underground-personnel building to support underground construction, a storage-exhaust-filtration building, an administration building, four shafts to the underground area, two mined underground horizons for the storage of contact-handled (CH) and remotely handled (RH) wastes, and various support structures: a warehouse and workshops, an emergency-power plant, a suspect-waste and laundry building, a vehicle-maintenance building, a sewage-treatment plant, and a water-supply system. In addition, there will be a mined-rock pile and an evaporation pond for sewage-treatment effluents. A construction-spoils disposal area and a sanitary landfill are also included in the design. Figure 8-10 shows the layout of the surface structures.

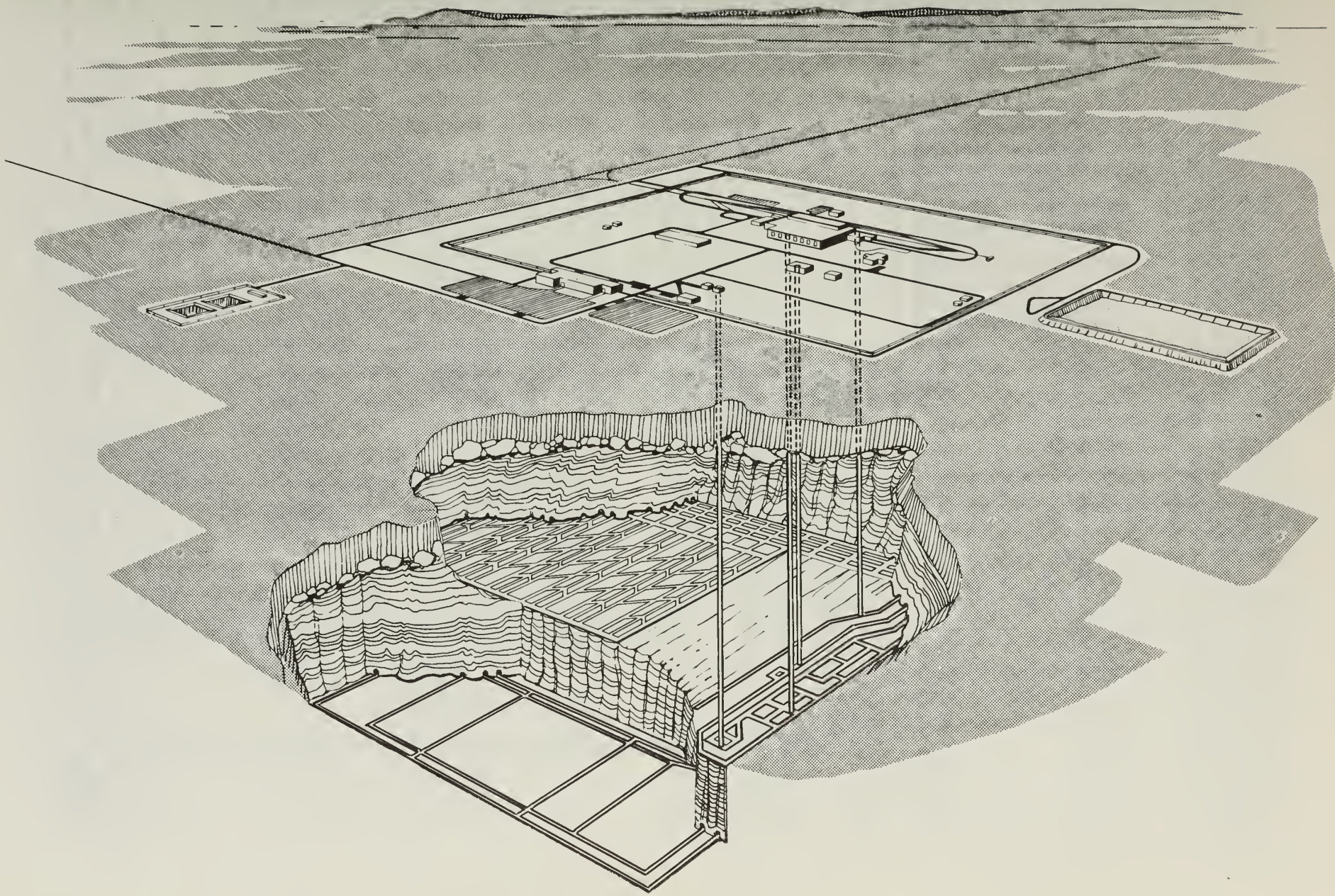

Figure 8-9. The WIPP reference repository.

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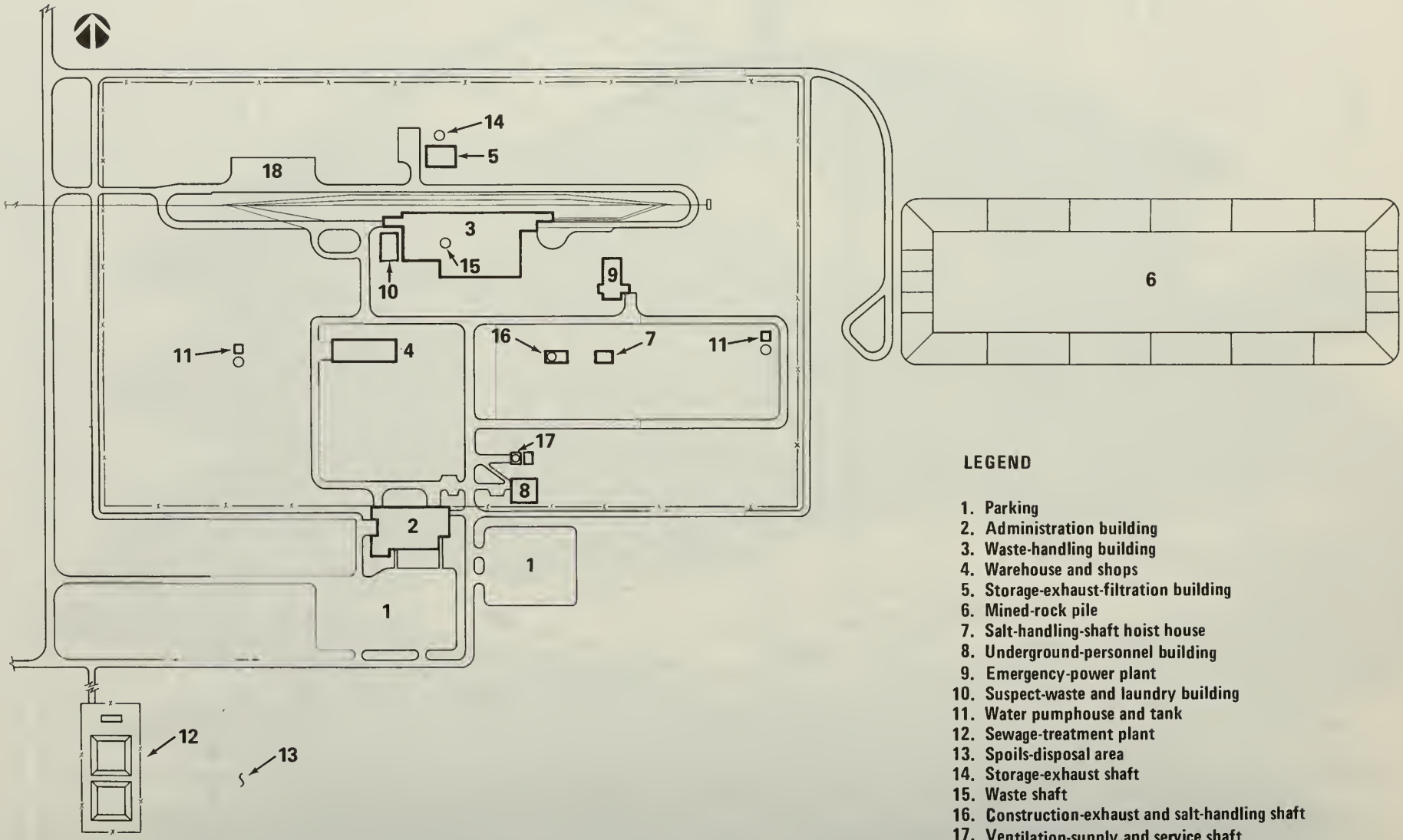

LEGEND

1. Parking
2. Administration building
3. Waste-handling building
4. Warehouse and shops
5. Storage-exhaust-filtration building
6. Mined-rock pile
7. Salt-handling-shaft hoist house
8. Underground-personnel building
9. Emergency-power plant
10. Suspect-waste and laundry building
11. Water pumphouse and tank
12. Sewage-treatment plant
13. Spoils-disposal area
14. Storage-exhaust shaft
15. Waste shaft
16. Construction-exhaust and salt-handling shaft
17. Ventilation-supply and service shaft
18. Transporter wash station

Figure 8-10. Surface structures and plant layout.

The plant will be constructed in accordance with the general design criteria of DOE Manual Appendix 6301, Part 1 (DOE, 1977). Surface buildings that will contain radioactive materials are designed to withstand the effects of credible earthquakes, accidents, and tornadoes to insure that both public health and safety and the environment are protected.

The surface structures consist of eight major buildings in an area of about 50 acres. Underground structures consist of four shafts and two waste-storage areas about 2100 and 2700 feet below the surface. Approximately 2000 acres will be used for underground storage.

8.2.1 Surface Structures

The principal surface structure is the waste-handling building (Figure 8-10). It is about 230 feet wide, 550 feet long, and 50 feet high (except for a 115-foot-high bay area). The building has separate areas for the receipt, inventory, inspection, and transfer of wastes through separate air-locks to a common waste shaft. Facilities for CH waste include a rail and truck shipping-and-receiving area, a receiving-and-inspection area, an inventory-and-preparation area, and overpack-and-repair rooms for damaged containers. For RH wastes there is a separate shipping-and-receiving area, an area for shipping-cask preparation and decontamination, a cask-unloading area, and a hot cell for waste-canister storage, overpacking, or decontamination. The waste-handling building also contains offices, change rooms, a health-physics laboratory, and ventilation-and-filtration equipment. Safety equipment and radiation-exposure control measures are included in the design of the waste-handling building.

The underground-personnel building contains support facilities for personnel working underground in construction and waste-handling operations (Figure 8-10). About 100 feet wide, 150 feet long, and 14 feet high, it is some 100 feet from the ventilation-supply and service shaft.

Other surface structures include the administration building (about 36,000 square feet), the storage-exhaust-filtration building (about 10,000 square feet) the vehicle-maintenance building (about 2300 square feet), a warehouse and shops (about 18,000 square feet), the emergency-power plant (about 10,000 square feet), the sewage-treatment plant, and the suspect-waste and laundry building.

A 30-acre area east of the plant (Figure 8-10) contains the mined-rock pile, which will store the rock, principally salt, excavated from the repository. The maximum height of the pile is 80 feet.

8.2.2 Underground Structures

The underground structures are on two levels (Figure 8-11). The upper level, 2100 feet below the surface, will receive CH waste for storage; it will cover about 170 acres when first developed. The lower level, 2700 feet below the surface, will contain three areas: one (10 acres) for the disposal of RH TRU waste, one (20 acres) for a demonstration of spent-fuel disposal, and one (20 acres) for experiments with high-level waste.

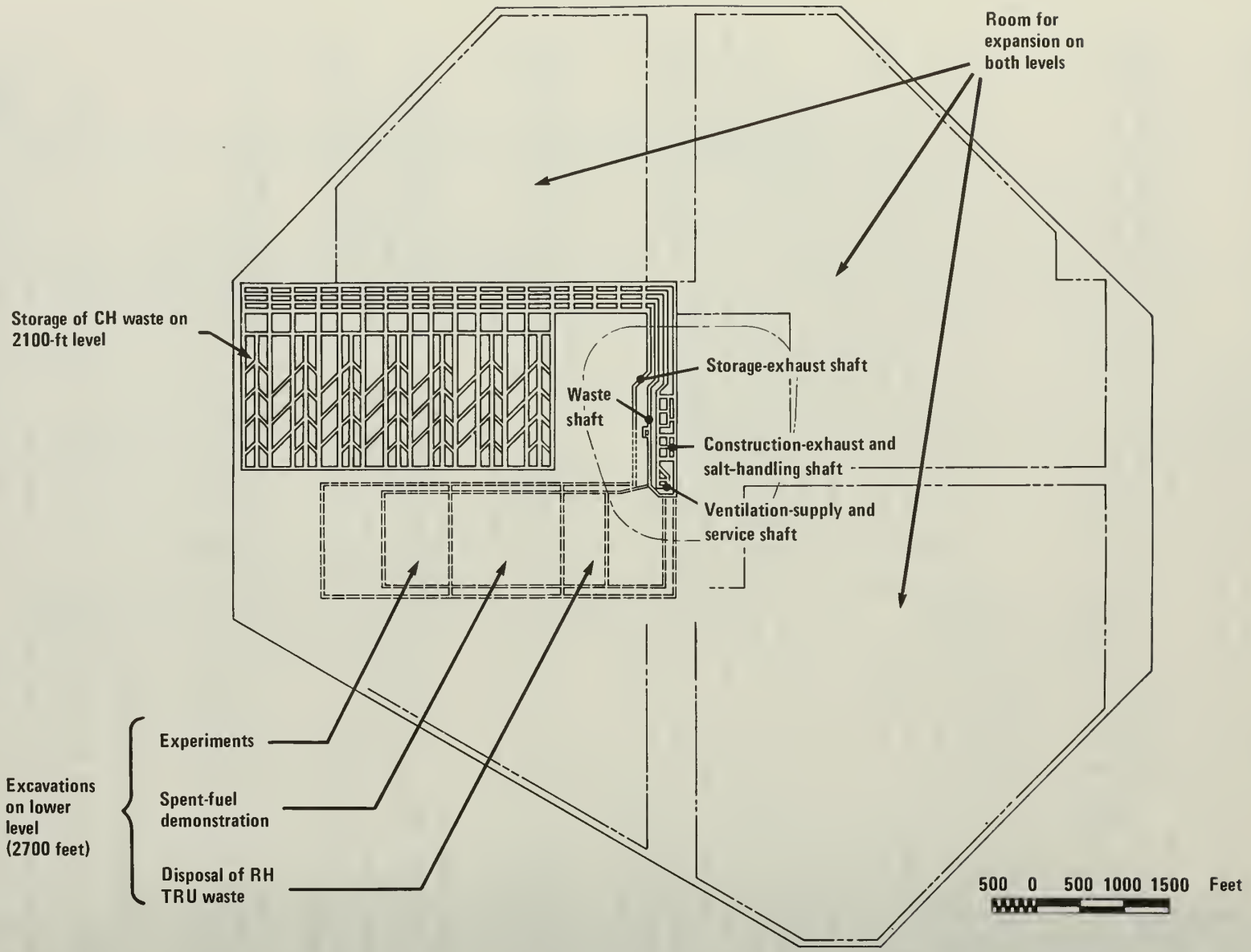

Figure 8-11. WIPP underground layout.

Both CH and RH wastes will be moved underground through the waste shaft in the waste-handling building. The other accessways to the underground storage areas are the ventilation-supply and service shaft for ventilation and movement of personnel and equipment, a construction-exhaust and salt-handling shaft to remove mined salt and exhaust air from mining operations, and a storage-exhaust shaft to exhaust air from the waste-storage area at each level.

Specially designed transporters will move wastes from the waste shaft to storage areas in each level. Underground workshops, warehouses, and equipment-storage areas are provided for the various pieces of mining and salt-transport equipment used in construction. An underground ventilation system supplies air to both the construction and the waste-storage areas; separate exhausts are installed for each area. Restrooms and other personnel facilities are also provided. To insure the safety of underground operations, safety equipment and radiation-exposure-control measures are included in the design of the underground facilities.

8.3 SURFACE FACILITIES AND OPERATION

8.3.1 Waste-Handling Building and Operation

The surface facilities will support the waste-storage operations. The major surface structure is the waste-handling building (Figure 8-12). It is centrally located and equipped to handle both CH and RH waste from the time it is unloaded until it is lowered through the waste shaft for placement underground. Separate areas are provided for handling CH and RH wastes. The larger portion of the building will be used for CH-waste unloading and loading, inventory, and preparation. A room is provided for overpacking and repairing CH-waste containers. A decontamination area, a cooldown-and-preparation room, and a hot cell are provided for RH wastes. Two independent airlocks are installed at the shaft entrance for wastes entering from the CH and RH areas. Filtration equipment for the waste-handling area, a laboratory, change rooms, and offices are also located in the waste-handling building.

Handling of CH waste

Contact-handled waste will be shipped to the plant in approved shipping containers by rail or truck. It will be unloaded with an overhead crane in the waste-handling building, through airlocks that control the movement of air during the unloading operations. The air in the waste-handling building will be maintained below atmospheric pressure to prevent contaminants from leaking to the outside air, even though no contaminants are expected to become airborne in significant amounts.

The CH waste will be received in 55-gallon drums, special boxes, or bins that have been transported in shipping containers. Once the shipping containers have been unloaded and the waste removed, the empty containers will be reloaded onto vehicles leaving the plant; the CH waste will be moved to the receiving-and-inspection area. There the CH-waste containers will be inspected. If found to be acceptable, they will be moved to the CH inventory-and-preparation area and then underground. If a container is found to be externally contaminated or damaged, it will be sent to the overpack-and-repair

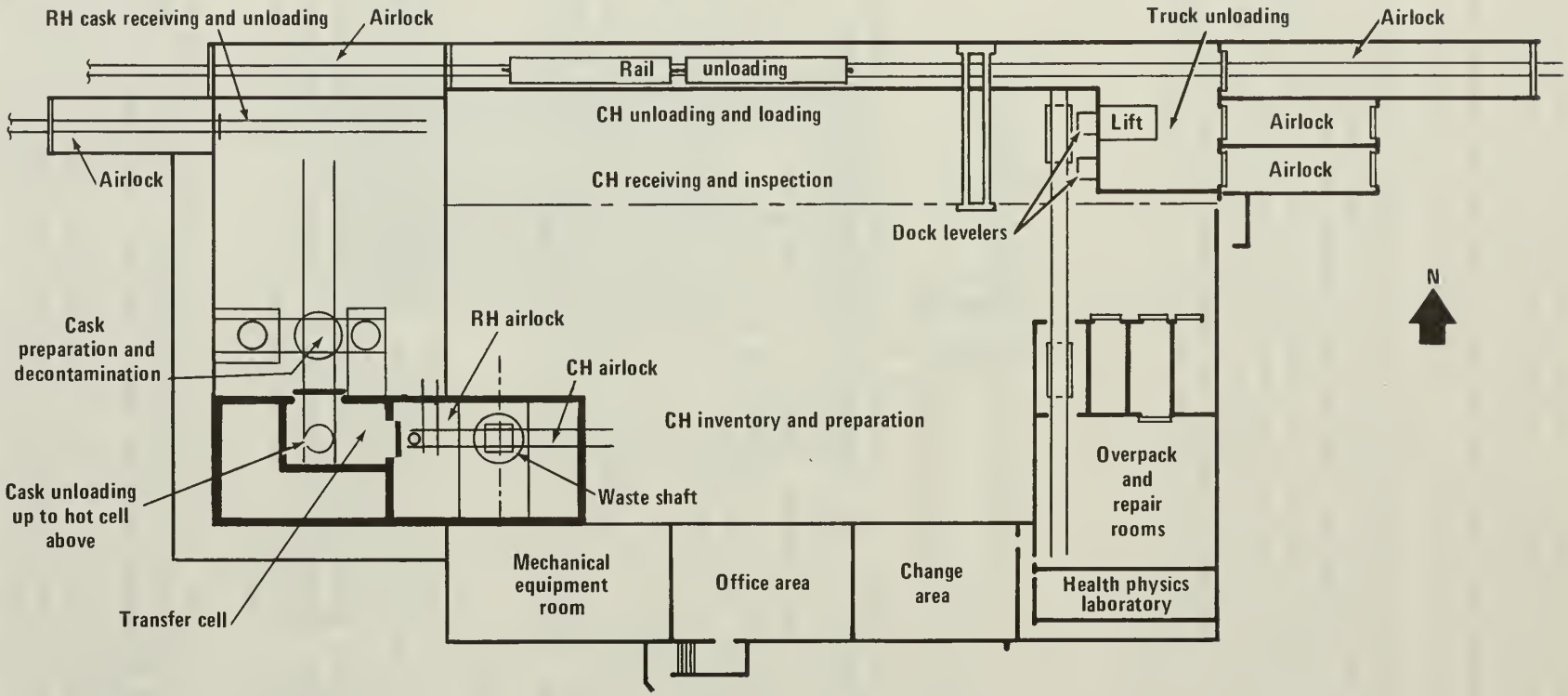

Figure 8-12. Floor plan of the waste-handling building.

room (Figure 8-12), where it can be decontaminated, repacked or recoated, and returned to the CH inventory-and-preparation area for transfer underground.

Handling of RH waste

Remotely handled waste will arrive in special shielded shipping casks, by rail or truck. On arrival, each shipping cask, which may contain one or more canisters of waste, will be inspected and unloaded from the railcar or truck in the cask-unloading-and-receiving area of the waste-handling building. If the railcar or truck is found to be contaminated, it can be cleaned and decontaminated in the transporter wash station outside the building. From there the cask will be moved to the cask-preparation-and-decontamination area, where any special operations such as cask cooling or attachment of handling equipment can be performed. Remotely handled waste will be handled from behind shielding and/or with remote-handling equipment. The RH-waste canisters will be unloaded from their shipping casks into the hot cell. After appropriate treatment, the shipping cask will be checked for contamination, decontaminated if necessary, and returned to the shipper for reuse. Canisters will be removed from the hot cell and loaded into the facility cask for transfer underground.

8.3.2 Facilities Supporting Underground Operations

The underground-personnel building provides facilities for personnel working underground: change rooms, showers, equipment storage areas, and offices. About 100 feet from the building is the ventilation-supply and service shaft and the hoist by which personnel and equipment will be moved underground. The storage-exhaust-filtration building adjacent to the storage-exhaust shaft contains equipment for exhausting and filtering the air from the underground-storage areas.

Mined rock (salt) will be brought to the surface through the construction-exhaust and salt-handling shaft adjacent to the salt-handling-shaft hoist house. Once at the surface, the mined rock will be moved by conveyor to the mined-rock pile outside the security fence. It is estimated that the pile will reach a height of about 80 feet (maximum) and cover about 30 acres.

8.3.3 Facilities Supporting Surface Operations

The administration building provides space for contractor personnel, visitors, and services; it is also the center of security operations and a control area for monitoring all activities at the site.

The emergency-power building contains the standby diesel generators and the necessary power switchgear. It also houses emergency support equipment, which includes air compressors, an air-filtration system, and fuel tanks.

The suspect-waste and laundry building adjacent to the waste-handling building houses the equipment, tanks, and controls for collecting and processing liquid radioactive wastes. It also contains a laundry for cleaning clothing worn in working with radioactive materials. Liquid radioactive waste will be collected from holding tanks for reprocessing in the suspect-waste and

laundry building. The reprocessed effluent will be either recycled or discharged to the radioactive-waste evaporator.

The warehouse and shops, the water pumphouses, the vehicle-maintenance building, and the sewage-treatment plant are buildings of standard design.

8.3.4 Environmental Control System

The environmental control system maintains a controlled environment for plant personnel and limits the discharge of radioactivity to the atmosphere. Included in it are heating, ventilating, and air-conditioning systems; air-cleaning and final discharge systems; and all related subsystems.

Plant personnel will work upstream from areas with higher potential for contamination. Access to these areas will be restricted. Pressure differences, maintained between separated areas in the plant and between these areas and the outside air, will insure air flow in the proper direction. To confine radioactive material, the air-cleaning system will pass the air through banks of high-efficiency particulate air filters. Monitors will warn of the presence of radioactivity in the airstream.

8.4 UNDERGROUND FACILITIES AND OPERATIONS

8.4.1 Waste Facilities

The underground waste facilities consist of the waste shaft, the waste-shaft hoist-cage system, and all facilities in the waste-storage areas.

Waste shaft

The waste shaft transfers CH and RH waste from the waste-handling building to the underground storage areas. The waste-shaft hoist cage will accommodate the RH-waste facility cask and the CH-waste containers to be handled at the plant. The hoist cage can handle a loaded pallet weighing about 30 tons.

The waste shaft is about 19 feet in diameter and 2700 feet deep. It extends 2100 feet from the surface to the CH-waste level and 600 feet from the CH-waste to the RH-waste level (Figure 8-13).

Storage of CH waste

The upper end of the waste shaft is in the waste-handling building (Figure 8-12). After a pallet is loaded, it will be transferred to the hoist cage, which will be lowered through the waste shaft to the underground CH-waste-receiving station. The hoist cage is a fully enclosed steel cage that is guided in its descent and ascent.

At the CH-waste-receiving station, an opening, about 20 feet high by 40 feet wide, allows access to the shaft. The pallet and the waste containers will be unloaded from the hoist cage onto a diesel-powered transporter for

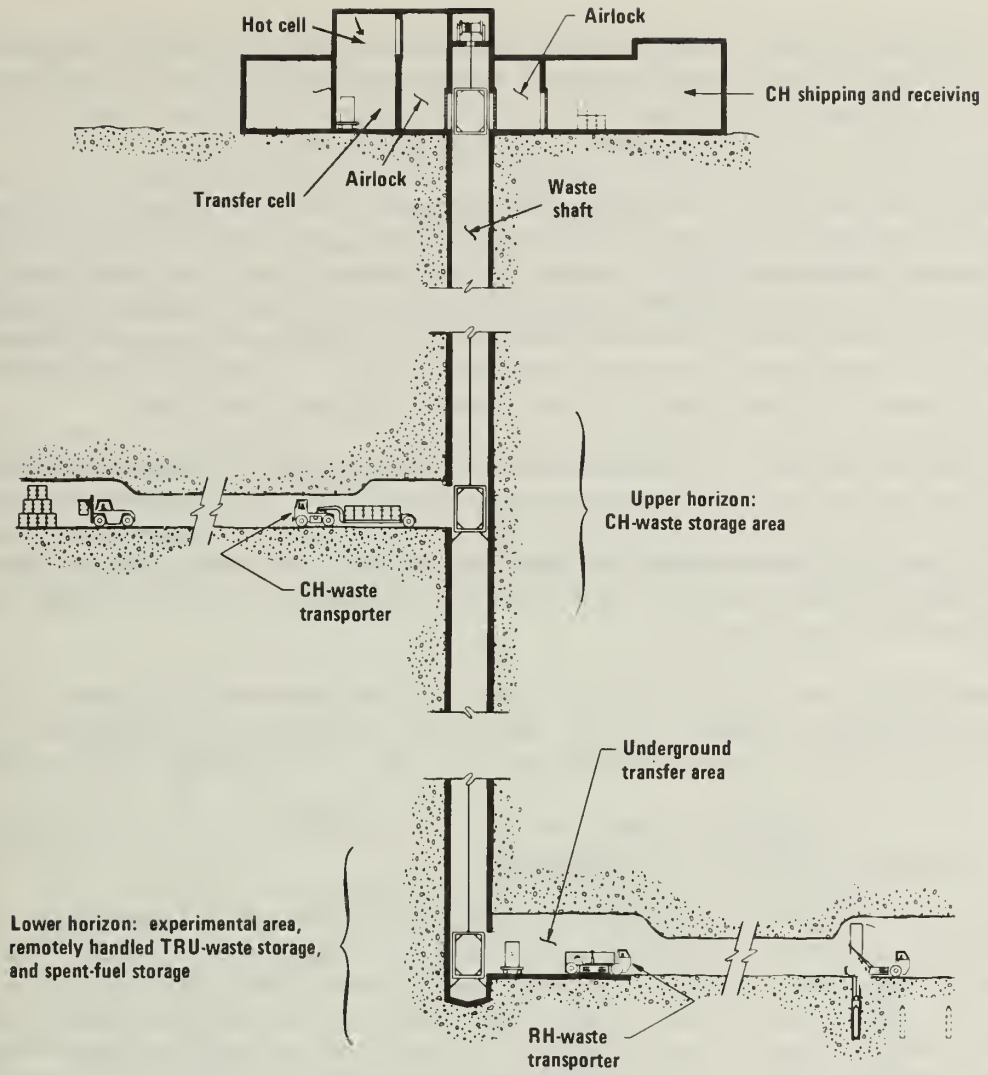

Figure 8-13. Waste shaft.

transfer to the CH-waste storage area. A decontamination and radiation-safety check station is located near the waste shaft on the CH-waste level.

The CH-waste storage area consists of four access tunnels and a number of storage rooms (Figure 8-11). Not all of the tunnels and rooms will have been constructed when the plant starts operating; the layout of the shafts and tunnels will allow mining and storage operations to proceed simultaneously. The first storage rooms will be ready when the plant begins operating and will be used to store waste while the next rooms are being mined.

A typical storage room on the CH-waste level is about 45 feet wide, 16 feet high, and 1600 feet long. Rooms are separated by pillars of salt.

Contact-handled waste will be stored in bulk except for a small quantity for experimentation. Records will be kept on all container storage locations.

Storage of remotely handled waste

The facility cask, holding RH-waste canisters, will be lowered in the hoist cage to the RH-waste transfer station at the lower end of the waste

shaft (Figure 8-13). Here it will be removed from the hoist cage and put into a holding position or loaded onto a waste transporter for transfer to the RH-waste storage area (Figure 8-11). Decontamination and radiation-safety check stations will be located close to the waste shaft.

The RH waste will be stored in a 10-acre array of rooms. The demonstration of spent-fuel disposal will be in an adjacent 20-acre area, and the high-level-waste experiments in a third 20-acre area. Not all the tunnels shown in Figure 8-11 will have been constructed when the plant begins receiving RH wastes. The shaft-and-tunnel arrangement will allow underground development and storage operations to go on simultaneously. A typical RH-waste storage room is about 14 feet wide, 24 feet high, and 500 feet long.

A diesel- or electric-powered waste transporter will move the facility cask from the shaft to a storage room, where the canister will be transferred directly from the cask to a storage hole below the storage-room floor (Figure 8-13). Special remote-handling procedures will be used through the emplacement of the canister in the salt. After emplacement, the storage holes will be plugged to floor level.

Backfilling with salt will be part of the permanent-disposal procedures. The emplacement procedure for RH waste not intended for permanent disposal will depend on the type of waste or the type of experiment being conducted.

8.4.2 Support Facilities Underground

The ventilation-supply and service shaft is used to move personnel, materials, and equipment between the surface and underground areas. In addition, the shaft supplies fresh air for the underground ventilation system (Figure 8-14). At each underground level workshops and warehouses near this shaft contain a repair bay, a welding bay, a lubrication bay, an electrical shop, a conveyor repair shop, several storage areas, and a warehouse. Offices and restrooms are also built at each level.

The construction-exhaust and salt-handling shaft is used to bring mined rock to the surface and to exhaust air from the mining-operations area at each level. The storage-exhaust shaft carries air from the underground storage areas to the storage-exhaust-filtration building.

8.4.3 Environmental Control System

The environmental control system (ECS) includes the ventilation and final discharge systems and all the associated subsystems. The general requirements for the underground ECS are similar to those discussed for the surface ECS in Section 8.3.4.

A schematic outline of the underground ventilation system is shown in Figure 8-14. The air supply to the underground areas enters through the ventilation-supply-and-service shaft and the waste shaft. At each of the two underground levels (CH and RH), the air flow is divided into two separate airstreams: one that supports construction (mining) activities, where there

is no potential for the release of radioactivity, and one that supports the waste-storage operations, where there is a potential for the release of radioactivity.

The method devised for separating the airstream will allow waste storage and construction activities to proceed simultaneously. Brattices will maintain the independence of the two ventilation airstreams. Pressure differences across the brattices will insure that all leakage through them flows to the areas that support waste storage. The brattices, made of fire-resistant materials, are designed to accommodate displacements from salt creep and seismic motion.

The construction airstream ventilates the construction areas, including the shops and warehouses at both storage levels. The air is exhausted through the construction-exhaust and salt-handling shaft to the atmosphere.

The storage-area airstream ventilates waste-storage areas and is exhausted through the storage-exhaust shaft to the underground-storage-filtration building.

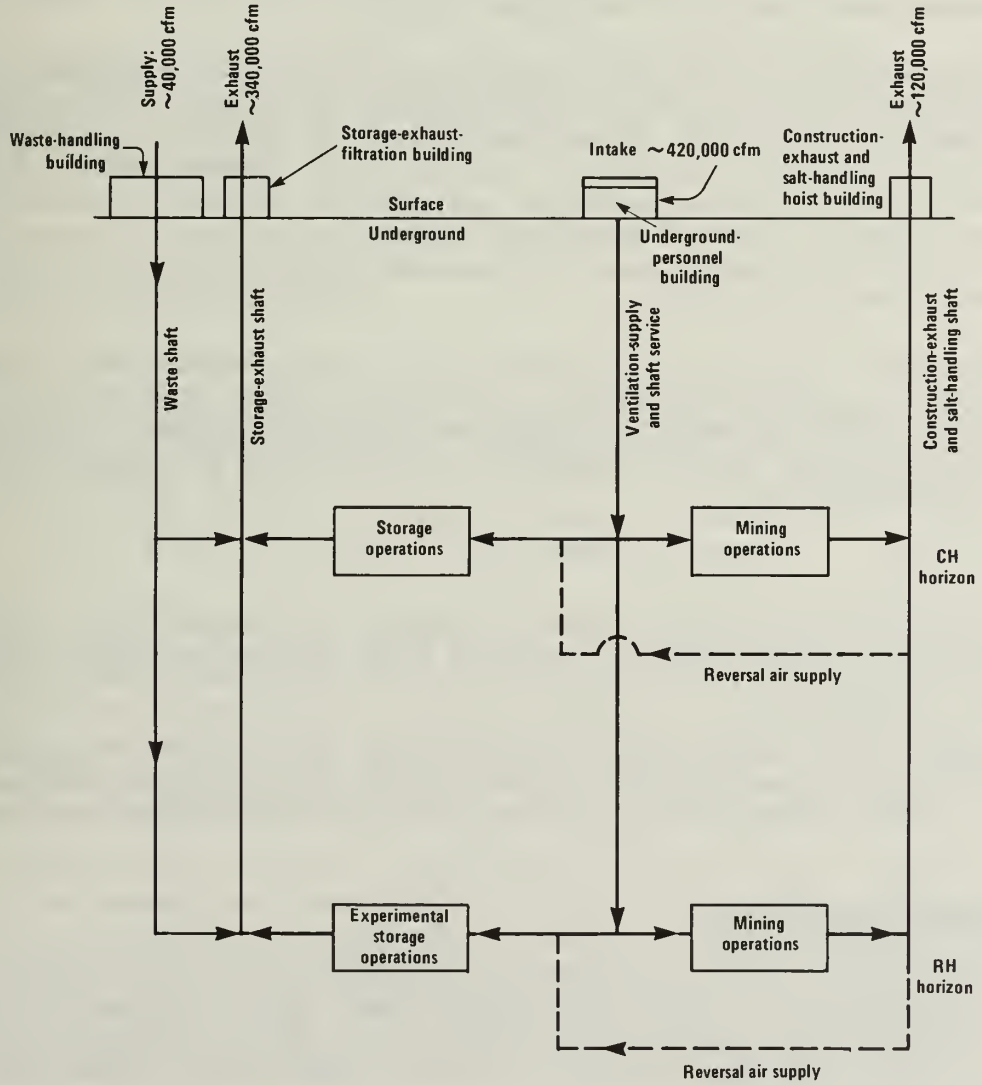

Figure 8-14. Underground ventilation flow.

8.5 SYSTEMS FOR HANDLING RADIOACTIVE WASTE GENERATED AT THE SITE

The radioactive-waste systems are designed to collect, process, and package radioactive waste produced by the plant. The waste-handling systems have enough surge capacity to handle waste produced during postulated accident conditions (Section 9.3.1.1) and by normal operations as well.

Plant-generated radioactive wastes will be liquids, like decontamination solutions; solids, like gloves, clothing, and filters; or gases, including airborne particulates. Appropriate systems will be provided to handle each type of waste.

8.5.1 Liquid Radioactive Waste

Sources and quantities

Liquid radioactive waste (radwaste) will be produced both daily and intermittently at several locations in the plant (Table 8-3) and will consist of either nondetergent radwaste or detergent radwaste.

In the waste-handling building, liquid radwaste will be produced routinely during shipping-cask cooling and decontamination operations. It will also be produced when a facility cask is decontaminated. In addition, small quantities of radwaste will be produced both routinely and intermittently in the laboratories. Periodic decontamination and washdown of facilities handling radioactive waste will produce additional quantities of liquid radwaste. In the event of a fire, large volumes of potentially contaminated water may result from fire-fighting efforts.

In the suspect-waste and laundry building, liquid radwaste will come from laundry operations. Additional small quantities will be intermittently produced by the decontamination of radwaste-processing equipment. In the underground operations, liquid radwaste will be produced principally by periodic decontamination.

Collection system

Liquid radwaste will be collected in tanks in the suspect-waste and laundry building and segregated in separate tanks holding detergent and nondetergent radwaste.

The radwaste from underground operations will be collected in portable tanks. Periodically, these tanks will be brought to the surface and emptied through a transfer system into the tanks of the liquid-radwaste-processing system.

Liquid-radwaste processing

The nondetergent liquid radwaste will be processed first by filtration and then by ion exchange in a mixed-bed demineralizer. After this purification process, the liquid will be moved to a collection tank for monitoring and evaluation. Water that meets recycle criteria, which specify permissible

Table 8-3. Estimated Rates of Production of Detergent and Nondetergent Liquid Radwaste

Source	Production rate (gal/month) Nondetergent	Detergent
Waste-handling area	11,000	100
Suspect-waste and laundry building	1500	4000
Underground operations	---	1500
Storage-exhaust-filtration building	200	---
TOTAL	12,700	5600

radioactivity levels, will be pumped to a recycle system for use in various decontamination operations. Excess water will be discharged to a radwaste evaporator. Water not suitable for recycle will be returned to the radwaste-processing system for additional purification. Recycled water will be used only in areas that normally contain radioactive materials.

The detergent liquid radwaste normally will have low levels of radioactivity. After processing to remove particulates, the liquid (which will be continuously monitored to insure compliance with regulatory requirements) will be pumped to the radwaste evaporator.

8.5.2 Solid Radioactive Waste

Sources and quantities

Solid radioactive waste will be produced in the waste-handling building, suspect-waste and laundry building, storage-exhaust-filtration building, and underground storage areas. An estimate of solid waste is given in Table 8-4. The solid radioactive waste consists of general process trash, ventilation filters, and by-products from the liquid-radwaste system.

Normal operation and plant maintenance will generate general process trash, the largest volume of solid wastes, including discarded protective clothing, cleaning rags, plastic bags, swipes used to check containers, and contaminated equipment parts. Dry solid waste will be segregated at its source into compressible and noncompressible waste. The compressible material will be transferred to a compaction station, compacted, and then sealed into drums. All noncompressible waste will be sealed into containers.

A probable source of solid radioactive waste resulting from normal operation will be contaminated ventilation filters. Filters from low-contamination areas will be handled by direct contact; protective clothing and respirators will keep personnel exposure as low as possible. Hot-cell filters can be replaced using remote-handling equipment. For disposal, filters will be packaged in special plywood boxes (DOT-7A) overcoated with fiberglass-reinforced polyester and lined with polyvinyl chloride and fiberboard.

Table 8-4. Estimated Annual Production of Solid Waste

Type of waste	Volume (cubic feet)	Number of 55-gal drums	Number of DOT-7A boxes[a]
Compressible waste	1200	200	---
Noncompressible waste	300	40	---
Cartridge filters	40	10	
Resins	460	70	
Ventilation filters[b]	1200		20
TOTAL	3200	320	20

[a]A 4 by 4 by 7-foot plywood box overcoated with fiberglass-reinforced polyester and lined with polyvinyl chloride and fiberboard; it is approved by the U.S. Department of Transportation.

[b]Uncompacted. Compaction would reduce the volume by approximately 75%.

The processing of liquid radwaste will generate by-products in the form of dirty filter-cartridge sludges (dry cake) and spent ion-exchange resins. These by-products will be packaged in drums for disposal.

Disposal of solid radioactive waste

Boxes and drums of the solid waste generated at the site may be disposed of in the repository. However, the form of this waste may not meet the chemical and physical criteria for acceptance at the repository, and the installation of a processing facility to handle the small quantities of site-generated waste may not be practical. If it cannot be packaged suitably for disposal at the repository, the solid site-generated waste may be shipped to another facility for processing and then returned to the repository for disposal.

8.5.3 Gaseous Radioactive Waste

Gaseous and airborne radioactive waste will appear in the ventilation systems, the special gaseous-radioactive-waste system, and the experimental-area gaseous-radioactive-waste system.

Ventilation air from surface buildings that might contain radioactive particulates will pass through a filtration system before release to the atmosphere. Consisting of prefilters and two stages of high-efficiency particulate air (HEPA) filters in series, the filtration system has a combined decontamination factor of 10^6 (American Association for Contamination Control, 1968). The release will be continuously monitored for radioactivity. The ventilation systems that will handle this air are located in the waste-handling building.

The radioactive-gas system will remove moisture and particulates from gases vented when shipping casks are opened and when overpack containers are

welded or tested for leaks. The cask-cooling system and the liquid-radwaste system may also vent gases into this special system. The gaseous waste will pass through HEPA filters before release to the atmosphere. This gaseous waste stream will be continuously monitored for radioactivity.

In the underground experimental area another system will remove particulates from gaseous waste produced in the underground experimental area. Gaseous waste from this system will pass through appropriate air-cleaning devices before release to the storage-exhaust system. This gaseous waste stream will be continuously monitored for radioactivity. The composition of the gaseous effluent released to the general ventilation system will depend on the experiments being conducted.

Mining operations will release radon isotopes that exist naturally in the mined rock. These gases will enter the underground-ventilation system and will be released to the atmosphere according to normal mining-engineering practice.

8.6 SOURCES OF POTENTIAL RELEASE OF RADIOACTIVE MATERIALS

During normal handling and storage operations at the plant, small amounts of radioactivity may be released. This section discusses the sources of these releases and predicts the amounts of radioactivity that may reach the biosphere. The predictions are the source terms for the analysis in Section 9.2.10, which evaluates the radiological impacts of the reference repository.

The discussion in this section characterizes the pathways for release according to five parameters:

1. Type of waste in a package.
2. Location inside the plant where the release occurs.
3. Origin of the released material: inside the package or on its surface.
4. Process by which the release occurs.
5. Filtration of the release.

Estimating the amount of released material requires, in addition to pathway descriptions, consideration of such details as container design, quality control, handling and transfer procedures, and storage methods. This analysis attempts to make realistic assumptions about such details. When data necessary for precise estimates are lacking, the analysis makes conservative engineering judgments; that is, it attempts not to underestimate the releases.

8.6.1 Release from Handling CH TRU Waste Above the Ground

Calculations of radioactivity-release rates from the normal handling of CH TRU waste were based on operation at three shifts per day and 5 days per week. The WIPP reference repository can handle approximately 1.2 million cubic feet of CH waste per year. The numbers of waste packages are 160,000 drums (55-gallon) and 2400 boxes per year.

The level of surface contamination on each container (drum or box) may vary significantly. Some containers will be clean; others may be at the maximum allowable level of contamination. In order to obtain an upper estimate of the radioactivity releases, it is assumed that all containers holding radioactive materials will have the maximum surface-contamination level permitted by the Department of Transportation (DOT) under Title 49 of the Code of Federal Regulations (CFR), Section 173.397. The handling of containers inside the waste-handling building will cause some of the removable (nonfixed) surface radioactive contaminants to become airborne. It is conservatively assumed that 10% of the surface contaminants (i.e., all of the radioactivity that could be removed by a wipe test as described in 49 CFR 173.397) on all containers will be released to the building atmosphere as a result of handling.

Normally, drums and boxes will be inspected for possible damage before shipment to the site. Only undamaged containers will be shipped to the site for storage. According to operating experience at the Idaho National Engineering Laboratory, the number of containers that suffer some sort of damage or have some undetected defects will be very small; of the damaged containers, many will be dented but not pierced. To derive an estimate of releases from damaged containers, 30 drums and 5 boxes each year are assumed to be damaged (or defective) and result in the release of radioactivity.

Radioactivity contained inside a damaged container may be released through cracks caused by rough handling. The cracks generated by dropping a 55-gallon drum during handling are assumed to be less than 1% of the total drum surface area. The amount of material released through cracks is assumed to be proportional to the ratio of the area of the cracks to the total area of the drum. Releases from damaged boxes are treated the same way.

Only a fraction of the material released from the damaged drum or box will become airborne. According to experiments with various waste forms (Mishima and Schwendiman, 1973), the fraction of the released waste (including particles that are of respirable and nonrespirable size) that becomes airborne is 0.00023 per hour. Under the assumption that 4 hours pass before the damaged waste package is brought to the repair area and the spilled waste is cleaned up, 0.1% (0.00023 x 4 x 100) of the released activity may become airborne. Particulates airborne in the building will be vented through the filtration system in the waste-handling building, which has a decontamination factor of 10^6 (American Association for Contamination Control, 1968). The radioactivity released to the environment will therefore be one million times less than the amount assumed to be airborne in the CH-waste area. The release sources and pathways are presented in Table 8-5.

The surface-contamination level and the internal-activity inventory per drum and box are based on 49 CFR 173.397. The annual release from the CH wastes via the ventilation exhaust is given in Table 8-6.

8.6.2 Release from Handling RH Waste Above the Ground

Three types of RH waste will be handled in the waste-handling building: defense RH TRU waste, high-level waste for experiments, and unreprocessed spent-fuel assemblies.

Table 8-5. Pathways for the Release of Radioactivity During Normal Operation[a]

Area	Release source	Release mechanism
	CONTACT-HANDLED WASTES (SURFACE FACILITY)	
Unloading and loading Inventory and preparation	Surface contamination of undamaged drums and boxes	Particulates become airborne during unloading or loading
Overpack-and-repair room	Surface contamination and contents leaking from damaged drums and boxes	Particulates become airborne during unloading, loading, and temporary storage
	CONTACT-HANDLED WASTES (UNDERGROUND)	
Storage-exhaust-filtration building	Surface contamination of CH drums and boxes	Surface contaminants are released to exhaust air during storage
	REMOTELY HANDLED WASTES (SURFACE FACILITY)	
Cask receiving and unloading	Surface contamination of casks	Particulates become airborne during unloading, loading, and transfer
Cask preparation and decontamination	Surface contamination of casks	Particulates become airborne during handling
		Particulates are released through through leaks in the gaseous-waste-handling system
Hot cell	Surface contamination of undamaged canisters	Particulates become airborne during unloading, transfer, and temporary storage
	Surface contamination and contents leaking from damaged canisters	Particulates become airborne during unloading, transfer, repair, and temporary storage
	REMOTELY HANDLED WASTES (UNDERGROUND)	
Storage-exhaust-filtration building	Surface contamination of RH containers	Surface contaminants are released to exhaust air during storage
	WASTE TREATMENT	
Suspect-waste and laundry building	Waste in treatment system for suspect waste and laundry	Particulates become airborne after partitioning from system leakage

[a]Except for underground operations, effluent treatment is provided by filters in the ventilation system (decontamination factor = 10^6).

Table 8-6. Releases to the Environment[a]

Isotope	Release (Ci/yr)			
	Surface Operations		Underground storage area	Total
	CH waste	RH waste[b]		
Tritium		4.5-1[c]	--	4.5-1
Fe-55		4.1-14	1.0-8	1.0-8
Co-60		2.8-11	7.3-8	7.3-8
Ni-63		3.1-14	7.8-8	7.8-8
Kr-85		7.8	--	7.8
Sr-90/Y-90		4.5-9	1.3-5	1.3-5
Ru-106/Rh-106		4.0-11	1.1-7	1.1-7
Cd-113m		1.1-14	3.4-10	3.4-10
Sb-125		3.5-11	1.2-8	1.2-8
I-129		7.5-7	--	7.5-7
Cs-134		6.5-8	1.6-7	2.2-7
Cs-137/Ba-137m		6.0-7	1.5-6	2.1-6
Ce-144/Pr-144		8.5-14	2.6-9	2.6-9
Pm-147		4.1-12	1.3-7	1.3-7
Eu-152		5.6-12	1.5-8	1.5-8
Eu-154		2.5-11	1.4-7	1.4-7
Eu-155		3.1-13	9.5-9	9.5-9
Po-212		5.7-18	1.8-13	1.8-13
Po-216		9.0-18	2.7-13	2.7-13
Th-228		9.0-18	2.7-13	2.7-13
Th-232		1.8-14	2.1-10	2.1-10
U-234		5.9-16	1.6-11	1.6-11
U-235		5.9-15	7.2-11	7.2-11
U-238		1.3-13	1.6-9	1.6-9
Np-237		1.8-16	5.6-12	5.6-12
Pu-236		1.7-17	5.3-13	5.3-13
Pu-238	2.4-10	3.1-12	2.3-5	2.3-5
Pu-239	2.8-9	1.8-11	2.6-4	2.6-4
Pu-240	6.8-10	4.6-12	6.4-5	6.4-5
Pu-241	3.6-8	1.2-10	3.5-3	3.5-3
Pu-242		7.6-16	2.3-11	2.3-11
Am-241	4.6-11	1.1-12	4.3-6	4.3-6
Am-242m		4.6-15	1.4-10	1.4-10
Am-243		1.0-14	3.3-10	3.3-10
Cm-242		3.8-15	1.2-10	1.2-10
Cm-243		1.7-15	5.3-11	5.3-11
Cm-244		1.0-12	9.5-7	9.5-7
Cm-245		2.2-16	6.6-12	6.6-12
Cm-246		4.3-17	1.3-12	1.3-12
Rn-220[d]			4.0-2[d]	4.0-2[d]
Rn-222[d]			9.0-1[d]	9.0-1[d]
TOTAL	4.0-8	8.3	3.9-3	8.3

[a]In the year of maximum release. This list includes only those isotopes that are significant contributors to potential doses.

[b]Includes releases from spent fuel, RH TRU waste, and experimental waste

[c]4.5-1 = 4.5 x 10-1.

[d]Treated separately in the impact analysis since not part of radwaste and therefore not included in table totals.

According to the WIPP design, 10,000 cubic feet of RH waste (about 260 canisters per year) can be handled in the building. About 75% by volume of the RH waste will be delivered to the plant by rail and 25% by truck. The RH waste will consist of contaminated trash (70%) and process waste (30%), which includes spent resins and solidified products of liquid-waste treatment. Because of its well-fixed form, process waste will make a negligible contribution to normal effluents in comparison with contaminated trash.

Loose particulates on the surface of the shipping casks used for RH TRU waste could, in theory, become airborne during the handling of contaminated casks in the cask-unloading-and-receiving area and the cask-preparation-and-decontamination area. Because the surface of each cask will be decontaminated before shipment to the plant, it will normally be nearly free of radioactive surface contaminants. It is assumed that 20% of the shipping casks will be contaminated and that 1% of the surface radioactivity of the contaminated casks will be released to the building atmosphere in the cask-preparation-and-decontamination area. (The surface contamination per unit area of a contaminated cask is conservatively assumed to be the same as the surface-contamination level of a waste canister.) It should be noted that the contribution of airborne surface contaminants to the building release is insignificant when compared with that of the internal leakage of damaged canisters, discussed below.

Shipping casks will be depressurized in the cask-preparation-and-decontamination area. Inert gas inside the cask will carry a small fraction of the surface contaminants of the canisters contained in the cask. During degassing, radioactive particulates will be released to the special gaseous-radioactive-waste system, where almost all of the particulates will be trapped by HEPA filters. Although the canisters will be decontaminated at their point of origin, it is conservatively assumed that 10% of the canister surface radioactivity will be released to the special system.

The loose surface contaminants released to the hot-cell atmosphere during hoisting are conservatively estimated to be 2% of the canister surface radioactivity since the canisters are thoroughly cleaned before shipping. Potentially, the most significant source of airborne activity in the hot cell will be internal leakage of damaged canisters. A canister is much less likely to be damaged than a drum or a box: the damage would have to occur inside a cask during shipping or in the hot cell during handling. It is a conservative assumption that one canister per year will have a crack covering 1% of the surface area of the canister. Assuming that the release is proportional to the area of the crack, 1% of the canister inventory will be released. If 4 hours pass before the canister is brought to the repair area and the spilled waste cleaned up, the amount of radioactivity that will become airborne is 0.1% (0.00023 per hour x 4 x 100) of the release (Mishima and Schwendiman, 1973).

Fewer than 300 canisters of high-level waste specially prepared for experiments will arrive at the plant over a period of 5 years. Because of the highly stable nature of this high-level waste, leakage from damaged or defective canisters will be negligible. Only the nonfixed surface contaminants of the contaminated canisters are available for release.

The spent-fuel demonstration will require fewer than 1000 spent-fuel canisters, shipped to the plant over a period of 4 years. Rough handling of

the shipping casks or canisters could damage some of the canisters and, in theory, even the spent-fuel assemblies inside. As a result, radioactivity could leak from the damaged fuel rods to the canister and from there out to the surrounding air. Because of the relatively small number of spent-fuel assemblies handled in the waste-handling building and the extra care in selecting spent-fuel assemblies and canisters for experiments, chances are small that a defective assembly will be selected for shipment or that a canister will be damaged in handling. This analysis assumes that one pressurized-water-reactor (PWR) spent-fuel assembly and its canister are damaged in the 4-year period. Realistic, yet conservative, release fractions based on the Reactor Safety Study (NRC, 1975) and NRC Regulatory Guide 1.25 are used in the evaluation. For the damaged fuel assembly, 1% of the fuel rods are assumed to have some cladding damage that allows radioactivity to be released. The release fractions from the damaged fuel rods into the canister are 30% of the tritium and krypton-85; 0.5% of the iodine-129; 1.5% of the cesium and rubidium; 0.01% of the tellurium, selenium, and antimony; and 0.0001% of the remaining nuclides. Ten percent of the nongaseous radionuclides released to the canister is released into the surrounding air; the remaining 90% is plated out on the inside surface of the canister. All the tritium, krypton-85, and iodine-129 gases are released from the canister. The amount of radioactivity released from a damaged spent-fuel assembly is greater than that released by any other source.

Airborne radioactive material from the handling of RH waste will be filtered. Although the double-HEPA-filter system has a combined decontamination factor of 10^6 for particulates, it will not filter out gaseous tritium, krypton-85, or iodine-129. Table 8-5 describes the release sources and pathways for the RH waste. The annual contribution of RH waste to the plant releases is given in Table 8-6.

It should be noted that most of the radioactivity released from RH waste is krypton-85 and tritium from the damaged spent-fuel assembly. The annual release from RH waste will be much smaller if there is no damaged spent-fuel assembly. The release of radioactivity will be much lower after the first few years, when the shipment of spent-fuel assemblies is terminated.

8.6.3 Release from the Suspect-Waste and Laundry Building

In this building, miscellaneous liquid radwastes will be collected, treated, and stored for recycle or evaporation, as described in Section 8.5.1. Estimates of radionuclide concentrations in these liquids and the amounts released from the plant are based on experience with liquid-radwaste-treatment systems at nuclear power plants. The concentration estimates assume that all external surface contamination on waste containers ends up in these liquid radwastes.

According to reactor experience, leakage from pump and valve seals in the nondetergent-waste-handling system will account for 0.5% of the total liquid-radwaste radioactivity. Of this, 0.1% is assumed to become airborne. The detergent waste stream is estimated to contain 1% of the total liquid-radwaste activity; this activity will become airborne during the evaporation process. Before discharge to the atmosphere, releases from the suspect-waste and

laundry building will be vented through the filtration system in the waste-handling building, which has a decontamination factor of 10^6.

Because the amount of radioactivity from the suspect-waste and laundry building discharged to the atmosphere is much less than the discharges from the waste-handling building, its radionuclide breakdown is not separately listed in Table 8-6.

8.6.4 Release from the Underground Storage Area

In general, the containers moved underground will be free from surface defects since damaged or defective containers will be repaired or overpacked in the waste-handling building at the surface. The only radioactivity available for release will be the surface contamination of the containers.

Although the surface contaminants will be fixed to the surface of the containers, hypothetical chemical changes are assumed to release them to the surrounding air during underground storage. The assumed release rates of this chemically altered, nonfixed surface contamination are 1% per year for CH waste and 0.5% per year for RH waste. Airborne surface activity in the underground storage area will be released to the atmosphere unfiltered. Annual release contributions from the underground storage area are given in Table 8-6.

Radon-220 and radon-222 are released in all mining operations, but the quantities released from mining salt are less than those from mining rocks such as granite or basalt. Radon-220 and radon-222 arise in the decay of naturally occurring rock constituents, thorium-232 and uranium-238, respectively. They are radioactive gases with such short half-lives (54 seconds and 3.8 days, respectively) that they normally decay into nongaseous isotopes before escaping from the rock structure. Mining, however, creates free surfaces that let these radon isotopes escape into the mine tunnels and thence to the open air by way of the ventilation system.

The releases from a repository in salt have been estimated to be as follows: radon-220, 0.04 Ci/yr; radon-222, 0.90 Ci/yr (NRC, 1976).

During the year that a spent fuel assembly and its canister are assumed to be damaged in handling, the release of krypton-85 and tritium will dominate radioactive releases from normal plant operation (Table 8-6). At all other times, radon-220 and radon-222 will dominate.

8.6.5 Release from Solid Waste Generated at the Site

Contaminated ventilation filters will be the largest single source of solid radioactive waste resulting from normal maintenance at the site. Although a portion of the airborne-particulate radioactivity will be precipitated onto the prefilters, most will be deposited on the HEPA filters. To estimate the amount of radioactivity on the filters, it can be assumed that all of the airborne radioactivity will be loaded onto the first stage of the HEPA filters. The first stage of the filtration system in the waste-handling

building will consist of 200 HEPA filters in parallel. When removed from use, the filters will be packaged 12 to a box.

The liquid-radwaste system will generate 460 cubic feet of spent ion-exchange resin per year. The spent resin will be packed in drums (an estimated total of 66 drums per year). Radioactivity per drum is calculated by assuming that all radioactive nuclides in the liquid-radwaste system will be loaded onto the ion-exchange resin.

Radioactivity per box and per drum for the solid waste generated at the site is shown in Table 8-7. The values given in this table represent an upper estimate of the radioactivity levels in each waste package. Actual radioactivity levels from different sets of filters will vary from negligible values to the values given in the table because, for example, the first set of filters in a series will remove more than 99.9% of the airborne particulates.

Table 8-7. Radioactivity of Solid Waste Generated at the Site

Isotope	Radioactivity (Ci) Per box[a]	Per drum[b]	Isotope	Radioactivity (Ci) Per box[a]	Per drum[b]
Fe-55	2.5-9[c]	3.0-8	U-235	3.5-10	2.1-10
Co-60	1.7-6	2.3-7	U-238	7.8-9	4.7-9
Ni-63	1.9-9	2.4-8	Np-237	1.1-11	1.7-11
Sr-90/Y-90	2.7-4	3.8-5	Pu-236	1.0-12	1.7-12
Ru-106/Rh-106	2.4-6	3.3-7	Pu-238	1.5-5	3.8-6
Cd-113m	6.6-10	1.0-8	Pu-239	1.7-4	4.4-5
Sb-125	2.1-6	3.8-8	Pu-240	4.1-5	1.1-5
Cs-134	3.9-3	4.7-7	Pu-241	2.2-3	5.6-4
Cs-137/Ba-137m	3.6-2	4.5-6	Pu-242	4.6-11	7.1-11
Ce-144/Pr-144	5.1-9	7.9-9	Am-241	2.8-6	7.7-7
Pm-147	2.5-7	3.8-7	Am-242m	2.8-10	4.4-10
Eu-152	3.4-7	4.4-8	Am-243	6.0-10	9.8-10
Eu-154	1.5-6	4.4-7	Cm-242	2.3-10	3.5-10
Eu-155	1.9-8	2.9-8	Cm-243	1.0-10	1.7-10
Po-212	3.4-13	5.5-13	Cm-244	6.0-8	2.9-6
Po-216	5.4-13	8.3-13	Cm-245	1.3-11	2.0-11
Th-228	5.4-13	8.3-13	Cm-246	2.6-12	3.9-12
Th-232	1.1-9	6.5-10			
U-234	3.5-11	4.8-11	TOTAL	4.3-2	5.7-4

[a]Two hundred HEPA filters for the first stage of the filtration system; 12 HEPA filters per box. The radioactivity per box is calculated as follows:

$$Ci/box = R(10^6)(12/200)$$

where R is the total particulate activity release from surface operations (see Table 8-6).

[b]Sixty-six drums of spent resin per year. The radioactivity per drum is calculated by assuming that all radioactive nuclides in the liquid-radwaste system are loaded onto the ion-exchange resin and then dividing this radionuclide inventory by 66.

[c]$2.5\text{-}9 = 2.5 \times 10^{-9}$.

8.7 NONRADIOACTIVE WASTE

Nonradioactive waste will be produced in mining operations, by the use and maintenance of equipment and facilities, and by the people working in the plant. This waste will be in the form of trash and refuse, mined salt, sewage, salt aerosols, emissions from burnt fuels, and some nonradioactive gases produced during experiments with high-level waste.

8.7.1 Sanitary Waste

During site preparation and the early stages of construction, chemical toilets will be used. After the sewage-treatment plant is completed, trailers equipped with restrooms and day tanks for waste storage will be used until the sanitary-sewage system is completed. The day tanks will be emptied at the sewage-treatment plant. The rate of sewage generation during construction is estimated to be 15,000 gallons per day (gpd).

During normal plant operation, the sources of sanitary waste will be toilets, showers, and sinks (including sinks in the health physics laboratory) and the cafeteria. It is estimated that the rate of sewage generation will be 25,000 gpd. Sanitary waste will flow to a sewage lift station, from which it will be pumped to the sewage-treatment plant.

The sewage-treatment scheme includes comminution, flow equalization, extended aeration (with sludge wasting), clarification, and chlorination. The sludge from the clarifier underflow will be further stabilized by aerobic digestion before transfer to the sludge-drying beds. The sewage-treatment plant will convert sanitary sewage with a biological oxygen demand (BOD) of 240 mg/l to a liquid effluent with a BOD of not more than 24 mg/l. The treated effluent will flow to an evaporation pond with a 5-day retention period. Most of the effluent will be used for landscape irrigation; the rest will be evaporated. It will meet applicable water-quality regulations (e.g., the New Mexico Water Quality Control Regulations). The dry sludge produced in the evaporation pond may be used as fertilizer or disposed of in the sanitary landfill, an area of about 5 acres outside the fence.

In the underground facilities either chemical or electrical toilets will be provided. If chemical toilets are used, the waste will be brought to the surface in tanks and either discharged to the sewage-treatment plant or hauled off the site for disposal. If electrical toilets are used, the final waste product will be in the form of ashes, which will be buried in the sanitary landfill.

8.7.2 Solid Waste

Trash

Most of the solid waste produced by the plant will be paper, rags, plastic materials, garbage from the cafeteria, wood scraps, sheet-metal scraps, tires, used batteries, and oily refuse. Metals and discarded equipment will be recycled through a commercial salvage company. All other materials will be

collected and disposed of at the sanitary landfill. At three work shifts per day, an estimated 2500 cubic yards of solid uncompacted waste will be produced annually. During the operating life of the plant, 63,000 cubic yards of solid waste will be produced.

At the sanitary landfill, solid waste will be buried in three levels separated by 12-inch layers of soil. Landfill will be performed by conventional means, such as the cut-and-cover method, using a crawler tractor with a dozer blade. To minimize water seepage into the buried material, drainage from the area around the landfill will be diverted by an interception ditch. A low-lying area will be selected to make the landfill unobtrusive, and natural revegetation of filled areas will be encouraged.

Mined rock

The salt removed from the mine will be stored in the mined-rock pile; much of it will be used later as backfill for the underground storage area. Assuming no salt is used for backfilling or is removed from the site, approximately 3 million tons would be produced during the operational life of the plant. To protect the stored salt from wind, the salt pile will be sprayed with water to form a protective surface crust.

8.7.3 Liquid Waste

Most of the liquid waste produced at the plant will be sanitary waste (Section 8.7.1). Other liquid effluents processed with the sanitary waste will be water used for washing miners' boots and nonradioactive filters.

Stormwater runoff from paved areas will be collected by storm sewers, which may also collect a very small amount of runoff from landscape irrigation; the rest of the irrigation water will run off and seep into the soil.

Estimated from rainfall-intensity data published by the National Weather Service, the maximum volume of runoff expected from the surface-facilities area is approximately 87,000 cubic feet after a 10-year-recurrence 30-minute rainstorm. This estimate assumes a water-infiltration rate of 80% and a surface area sufficiently large for the spoils-disposal area and future surface facilities. Runoff will be caught in a ditch surrounding the plant, directed to the outside of the surface facilities, and discharged to seep into the sandy soil.

8.7.4 Chemical and Biocidal Waste

Since no chemical processing will be used at the plant, there will be no appreciable chemical effluents. Residual chlorine levels from the treated sewage-plant effluent will be insignificant. The small quantities of waste hydraulic fluids, lubricants, and the like that will be produced during plant operation will be buried in the sanitary landfill or sent away for salvage. No biocidal waste will be discharged since none will be used.

8.7.5 Airborne Effluents

Airborne effluents will consist of fugitive dust from mining, small gas releases from experiments with waste, fumes and particulates emitted by fuel-burning equipment and motor vehicles, and wind-blown dust from the mined-rock pile.

Salt aerosols

Salt dust produced in mining operations has been classified as "nuisance dust" by the American Conference of Governmental and Industrial Hygienists (ACGIH), with the allowable concentration (threshold limit value) set at 10 mg/m^3 (ACGIH, 1977; 30 CFR 57). Air samples from potash mines in the Carlsbad area show that the actual concentration of particulates in mine air is approximately 265 g/m^3. If 120,000 cfm of such air is discharged through the construction-exhaust shaft, the discharged air will contain salt particles and the amount released will be 1050 lb/yr.

Gases from underground waste experiments

Gases from waste experiments will consist of small amounts of hydrogen from the corrosion of containers and the hydrolysis of brine, helium from radioactive decay, and hydrogen chloride from brine decomposition. The total quantity of these experimental wastes may be nearly 400 cubic feet. It has been estimated (NRC, 1976, Table IV H-16; Bishop and Miraglia, 1976, Table 4.15) that a hypothetical high-level-waste (HLW) and TRU-waste repository containing about 2 million cubic feet of high-level waste would generate 4 standard cubic feet per minute (scfm) of hydrogen, 0.001 scfm of helium, and 0.07 scfm of hydrogen chloride. These quantities should be divided by 5000 (2,000,000/400) to produce an estimate for the WIPP reference repository. The results are shown in Table 8-8.

Table 8-8. Estimated Release Rates of Nonradioactive Gases from HLW Experiments

Gas	Gas-release rate[a]	
	scfm	kg/yr
Hydrogen	8×10^{-4}	1.1
Helium	2×10^{-7}	0.0005
Hydrogen chloride	1.4×10^{-5}	0.34

[a]Based on estimates by the NRC (1976, Table IV H-16).

Fumes from burnt fuel

There will be three principal sources of fumes from burnt diesel fuel: the emergency-power system, the surface handling equipment, and the underground handling equipment. In addition, an oil-fired drier will be used to

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Table 8-9. Estimated Emission Rates[a]

Pollutant	EPA emission factor (g/hp-hr)	Total (kg/yr)
EMERGENCY POWER PLANT		
Carbon monoxide	3.03	2,700
Hydrocarbons	1.12	980
Nitrogen oxides	14.00	12,000
Sulfur dioxide	0.93	800
Particulates	1.00	880
SURFACE HANDLING EQUIPMENT[b]		
Carbon monoxide	2.62	2,600
Hydrocarbons	0.85	870
Nitrogen oxides	14.9	14,700
Sulfur dioxide	0.89	900
Particulates	0.78	770
UNDERGROUND HANDLING EQUIPMENT[b]		
Carbon monoxide	2.62	1,800
Hydrocarbons	0.85	600
Nitrogen oxides	14.9	10,400
Sulfur dioxide	0.89	600
Particulates	0.78	500
MINED-SALT DRIER[b] (lb/10^3 gal)		
Carbon monoxide	5.0	1,700
Hydrocarbons	1.0	400
Nitrogen oxides	22.0	7,900
Sulfur dioxide	71.0	23,800
Sulfur trioxide	1.0	400
Particulates	2.0	700

[a]Based on factors published by the EPA (1977).
[b]Emission rates based on one 8-hour work shift per day.

dry the salt stored on the surface for backfilling the repository. Table 8-9 shows the calculated annual emissions. The calculations were based on emission factors published by the U.S. Environmental Protection Agency (EPA, 1977) and on the following assumptions: The emergency-power diesel-generator plant, with an installed capacity of about 10,000 horsepower, will be used 1% of the time (88 hours per year). The diesel-powered surface handling equipment (about 3400 horsepower) will be used about 10% of the time (2720 horsepower-hours for each 8-hour shift). The underground handling equipment (about 600 horsepower) will be used about 40% of the time. The salt drier

(approximately 30 million Btu/hr) will be used during each work shift after about the sixth year of operation.

Wind erosion

Dust will be dispersed to the atmosphere because of construction activities, wind erosion of the mined-rock pile, and naturally occurring soil erosion. To minimize erosion and dust generation, the areas likely to produce wind-blown dust will be sprayed with water. Erosion of the mined-rock pile will be controlled by applying small amounts of water to promote the formation of a crust. Projected erosion rates and estimates of salt dispersal are discussed in Section 9.1.3. Since all areas used by vehicular traffic are paved, the amount of dust caused by the movement of cars or trucks will be minimal once the plant is completed.

8.8 AUXILIARY SYSTEMS

Besides the water and power systems, the plant's auxiliary systems include roads, railroads, and communications systems.

8.8.1 Water

The estimated peak 8-hour demand for water at the plant is 25,000 gallons (52 gpm) during daily use and 190,000 gallons (400 gpm) during firewater make-up to the on-site storage tanks.

The water for the plant will be purchased from, and delivered by, the Double Eagle Water System, which consists of a series of wells about 35 miles north-northeast of the site. The system has a 542-gpm reserve pumping capacity and a storage capacity of 336,000 gallons. It is expected that this system will be expanded by drilling new wells to meet future requirements.

The tie-in point for the new line to the site is on the Eddy/Lea County line at an existing 10-inch main. A proposed new 24-inch line will run due south from the tie-in point for about 18 miles to the Carlsbad/Hobbs highway (U.S. 180) and continue along the site access road for another 13 miles, terminating at two on-site storage tanks.

8.8.2 Power

Most of the energy used at the plant will be electrical power purchased from a commercial utility company. Except for the fuel used by diesels, other automotive engines, and the salt drier, fossil fuel will normally not be used.

Electrical power will be provided by the Southwestern Pacific Service Company (SPSC) from generating stations near Carlsbad and Hobbs, New Mexico. A new 115-kilovolt transmission line will be extended from an SPSC switching

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station to the site. This tie-in will be about 10 miles west of the center of the site on an existing 115-kilovolt line along a 75-foot right-of-way.

8.8.3 Roads

Present access to the site is by a crude caliche-surfaced road, extending from New Mexico highway 128 to the site. The principal access to the site will be on a new road built from U.S. 62/180, about 13 miles north of the site. This road will be built to State highway standards. A second road will reach New Mexico highway 128, about 4 miles south of the site. Both roads will require a 200-foot right-of-way.

The routing of on-site roads (Figure 8-10) supports the waste-handling operations. These roads are designed for the movement of cask-containing waste transporters and the routine flow of maintenance vehicles. Vehicles will enter only through entrance gates. On-site parking is provided for employee vehicles, site-maintenance and staff vehicles, and waste-transportation vehicles.

8.8.4 Railroads

Railroad access to the site is required for receiving waste shipments by railcar. The proposed rail line to the plant originates from a spur at the Duval Corporation Mine, about 6 miles west-southwest of the site (Figure 8-6). It will require a right-of-way of approximately 100 feet.

On-site tracks are required for the efficient movement of railcars brought to the site. The on-site railroad layout, shown in Figure 8-10, provides a siding for railcar transfer from locomotives to plant railcar movers, individual CH- and RH-waste railspurs for access to the waste-handling building, and parking space for about 30 railcars.

8.8.5 Communications

The communication systems for the site are interconnected (a) to insure that no operation will become isolated from the central control point and (b) to provide for communication with off-site emergency services, such as ambulances, fire fighters, and local law-enforcement agencies. These communication systems may include telephone, radio, public address and intercom, and closed-circuit television.

Telephone service will be provided by the General Telephone Company of the Southwest from Carlsbad. The total length of new off-site cable is approximately 40 miles.

8.9 EXPERIMENTAL AND DEVELOPMENTAL PROGRAMS

As a part of the reference mission described in Section 1.2, the WIPP will include a test bed for in-situ experiments on the interactions of high-level waste (including spent fuel) with bedded salt. A specially designed part of the underground workings will be used as a place for experiments; the small amount of waste used in these experiments will be removed at the end of the program. In addition, the project will include several other underground activities that can also be broadly characterized as development efforts: the further development of storage and handling methods will be supported by demonstrations and by monitoring the mine structure; contact-handled waste will be monitored to confirm the safety of the methods used in storing it. Because the experiments and the development programs cannot begin until after the first shaft has been sunk, no earlier than 1982, they are now in early design stages. This section describes the current plans for them.

These studies in the WIPP reference repository are only a part of a larger program that includes laboratory investigations, bench-scale studies in large blocks of salt, a series of preliminary measurements in existing mines, and development of analytical models that predict the behavior of a repository. Much of this extensive "pre-WIPP" program has already begun, and most of it will be complete before the repository opens. As explained in the following discussion, the investigations in the WIPP mine will be extensions of the earlier studies. The WIPP studies will establish whether the results of the earlier experiments are valid in an actual repository, and they will check the analytical models.

8.9.1 Structural and Engineering Activities

Although the techniques used to construct the underground workings will be conventional, the operations subsequently carried out there will produce some unconventional stresses in the mined structure. In addition to the stresses normally present in mined cavities, heat-induced stresses will appear in areas where heat-producing waste is placed; extensive boring of test holes and emplacement holes in the sides and floors of some cavities may produce other unusual stresses and stress concentrations. To insure the development of efficient techniques and safe operations, the studies will include

1. Monitoring of dimensions and strains in the underground rooms and pillars, beginning immediately after excavation.

2. Studies of the physical characteristics of rock samples. These studies will test the applicability of more extensive earlier measurements on core samples.

3. Monitoring of mine structure in areas where contact-handled waste is stored.

4. Extensive monitoring of structural changes in areas where heat-generating waste and other sources of heat are present. Some of these studies may use electrical heaters to simulate or to supplement the thermal output of stored wastes.

Another part of the experimental and development program will refine and demonstrate techniques for handling, emplacing, and retrieving waste. Engineering studies planned for this purpose include

1. Retrievability studies. Techniques and machinery for emplacing remotely handled waste in retrievable configurations are already being developed and will be tried out in the pre-WIPP program. Demonstrations of retrievability in the repository will include actual recovery of previously buried canisters of remotely handled waste.

2. Studies of shaft and hole plugging. In developing methods for sealing a decommissioned repository, experiments will study various materials and techniques for plugging the mine shafts and preventing future cracking or leaking in the seals. These studies will also examine the tendency of the shaft walls to develop stress-relief cracks. Most of this work will have been carried out by the time the repository opens.

3. Measurements of gross thermal properties of the salt medium, providing in-situ checks of previous laboratory measurements on core samples.

4. Studies of hole closure and sloughing. Emplacing and retrieving waste in a well-engineered manner will require knowledge of the rates at which holes bored in the salt will close themselves and slough material from their sides. The studies in the repository will check earlier laboratory results.

5. Studies of the routine handling of waste. This work will include full-scale demonstrations of the methods used to move waste containers through the plant and to bury them underground. Continued development of safe and efficient techniques is the goal.

8.9.2 Monitoring of Contact-Handled Waste

Purpose and status

Studies carried out before the repository opens will furnish detailed information on the properties of contact-handled TRU wastes and on the interactions the wastes will undergo in a bedded-salt repository (Molecke, 1978a). This work will help to establish the final criteria that will govern the acceptance of such wastes at a repository.

Most of the required studies can be performed adequately in laboratories; many of them are already in progress, and most will be complete by the time the repository opens. Some additional monitoring will be performed in the underground workings in order to test whether the laboratory results are valid under actual repository conditions.

The studies planned for contact-handled waste are discussed below. For completeness, the discussions also mention briefly the studies that will be carried out before the repository opens. Detailed descriptions and results of all the work will appear in reports to be issued as the program develops.

Flammability studies

A series of studies will seek to establish acceptance criteria that will lessen the severity and consequences of a fire and minimize its probability. Flammability studies of existing waste and waste containers (by the Idaho National Engineering Laboratory and by Sandia Laboratories) have begun; some of this work has already been completed. All of the flammability studies are being done in laboratory tests; none are planned for the reference site.

Studies of gas generation

As the wastes age and degrade, they can produce gases through four processes: chemical interactions, radiolysis, thermal degradation (including pyrolysis), and bacterial action. Studies of gas generation by the four mechanisms are being carried out predominantly in laboratories and through bench-scale experiments in salt blocks. Activities proposed for the underground workings include

1. Determination of the quantity and nature of gases, including water vapor, generated by stored waste. Toxic, flammable, explosive, and radioactively contaminated gases will be monitored through the operational phase of the WIPP project.

2. Study of salt permeability to the gases that the waste is likely to generate. Laboratory experiments are already under way; studies in an existing salt or potash mine are in the planning stage. Monitoring in the mine will check the earlier results.

3. Determination of the effects that water vapor produced by heat and pyrolysis may exert on the minerals and equipment in the mine.

4. Study of synergistic effects due to the simultaneous generation of gas by more than one of the four processes. This work will involve careful assessment of effects produced when waste is stored under conditions that simulate the adverse effects of overburden pressure and water intrusion: a controlled amount of water will be intentionally introduced as a leachant into a small backfilled storage chamber containing contact-handled waste in deliberately damaged containers. This study will take place in the mined area devoted to experiments.

Studies of radionuclide movement

In order to predict processes related to the long-term safety of the repository, a consequence analysis is being prepared. This analysis includes a model of possible failure modes for a repository (Section 9.5.1). Some of the data needed for the detailed failure model are not available in thorough, quantitative form; the studies of contact-handled waste will help to supply these data through the following investigations:

1. Study of the physical integrity of waste packaging.

2. Study of leaching of the waste. These studies will determine the extent to which water can mobilize radionuclides from combustible and noncombustible wastes and from waste matrices now under development. Measurements in the experimental area will be designed to check the extensive laboratory work now in progress.

3. Study of actinide mobility. Parameters include the chemical composition of geologic formations and of brine, the presence and effects of organic ligands, and the effects of "getter" materials that retard the migration of nuclides. These studies are already under way in laboratories and will be checked by less-extensive in-situ monitoring.

8.9.3 Experiments with High-Level Waste: General Considerations

Experiments with high-level waste constitute a basic mission of the WIPP reference repository. These experiments are not so much concerned with the WIPP itself as they are with planning future high-level-waste repositories. They are to answer technical questions about the disposal of high-level waste in bedded salt. High-level waste generates more intense heat and radiation than do other types of waste, especially in its first several hundred years, before fission-product nuclides have decayed to insignificance. Thus it affects its burial medium more severely than other wastes do. As many as possible of the high-level-waste experiments will be performed in laboratories rather than in the WIPP mine, but a thorough investigation cannot be carried out by laboratory study alone (OSTP, 1978).

Studies of the interactions of waste with bedded salt were performed between 1965 and 1967 during Project Salt Vault, a project in bedded salt near Lyons, Kansas (Bradshaw and McClain, 1971). The WIPP high-level-waste experiments will build on the knowledge gained from Salt Vault and from later laboratory studies. Using advanced instruments and techniques, they will significantly expand the earlier data and will also include several studies, especially chemical studies, that were not part of Salt Vault.

The basic goals of the WIPP experiments and the accompanying laboratory experiments are to study (1) the effect of the high-level waste on the surrounding salt, (2) the changes that will occur in the buried waste as it interacts with the salt, (3) the movement of radionuclides out of the waste, and (4) the subsequent transport of these radionuclides, especially by any circulating groundwater present.

The experiments with high-level waste will use material originating in defense programs and in commercial electric-power generation. Commercial nuclear waste is more intensely radioactive than waste produced in defense programs; it is therefore preferable for the WIPP experiments. Because, however, no commercial waste will be reprocessed for the indefinite future, special preparation in prototype or defense processing plants may be necessary to provide the waste needed for the WIPP high-level-waste experimental program.

A fundamental problem in these studies will be the great difference between the duration of the experiments and the duration of the processes the experiments are to elucidate. The experiments may continue for several decades, but the processes in an actual repository may continue for thousands of years after it has been filled. To identify the mechanisms that will produce long-term effects, the program will include some efforts to accelerate these processes. Some experiments can, for example, use amounts of water or heat that are greater than those expected in a repository; the effects on the waste and the salt will then be hastened or at least intensified. This kind of experiment is not a direct simulation of the aging of a repository, but

careful analysis of its results should help in identifying and modeling the important long-term processes. The experimental program will also include some experiments using high-level-waste materials that have been broken or ground into small particles. Such material will simulate degraded waste as it may appear long after burial, when the disintegration of containers has exposed waste material directly to the salt.

8.9.4 Experiments with High-Level Waste: Specific Plans

Plans for the in-situ experiments with high-level waste are in a preliminary stage. Details of the designs (Molecke, 1978b) will change as they are elaborated and refined during the years before the repository is ready for underground experiments with radioactive material, no earlier than 1986; laboratory and bench-scale studies performed during that time will guide the changes. Because the preliminary plans nevertheless reveal the scope of the experiments, this section outlines them.

All of the experiments listed here will be additions to the pre-WIPP laboratory work, much of which is already in progress. The studies performed in the repository will include tests of earlier results and a few other types of experiments that can be carried out only in actual underground workings. Molecke (1978b) gives further details.

Studies of radionuclide transport and migration

The experiments now planned include

1. Studies of nuclide transport through bedded salt and surrounding rock by means of brine migration.

2. Studies of the ability of brine to leach radionuclides from waste. To accelerate this slow process, the experiments will include the leaching of "bare" waste (not protected by packaging material) that has been broken into small pieces.

3. Studies to determine how leach rates are affected by the heat, radiation, pressure, and chemical species present in a repository and by the radioactive-decay process.

4. Studies of ion-exchange processes and of "getter" compounds (materials that selectively sorb particular nuclides or react with them). These studies will help to develop additional barriers to nuclide migration.

5. Measurements of thermally driven solid-state diffusion, a mechanism for nuclide transport along grain boundaries in the salt.

6. Proof tests of emplaced canisters. These studies will measure the ability of waste canisters to retard leaching and subsequent nuclide transport. Tests will include measurements with normal undamaged canisters and with deliberately damaged canisters. They will also investigate the use of sleeves or coatings on the canisters for extended corrosion resistance.

7. Measurements of gas-phase nuclide transport, which results from the volatilization of waste material. This process might occur in a future repository containing spent fuel, which produces gaseous fission products.

Studies of chemical effects

Planned experiments include

1. Determination of the composition and quantity of fluid inclusions in the experimental horizon, measurement of their rate of migration under different thermal gradients, and detailed study of the consequences of such migration.

2. Studies of the chemical and sorptive properties of getter materials to determine their effectiveness as an additional barrier to radionuclide transport.

3. Studies of canister and sleeve corrosion as functions of brine composition and chemistry, metallurgical composition, temperature, pressure, and radiation damage. These studies will be limited to testing previous laboratory results.

4. Monitoring of gases produced through radiolysis and corrosion.

Studies of physical effects due to heat, radiation, and pressure

Planned experiments include

1. Measurement of energy stored in the salt through the "metamict" or Wigner effect, which occurs when irradiation of the salt surrounding a waste container creates radiation-damage sites in salt crystals. The thermal fields that accompany this radiation tend to anneal the salt and prevent a buildup of stored energy. The annealing effects, however, vary strongly with temperature. Laboratory studies are measuring stored energy in a salt as a function of temperature, pressure, and gamma-ray and neutron fluences; the underground experiments will be a small effort intended to establish whether the earlier results are valid in situ.

2. Measurement of the variations induced by heat, radiation, and pressure in bulk physical properties such as thermal conductivity, strength, and viscosity.

3. Investigation of the effects of these variations on the mobility and buoyancy of salt and waste canisters.

8.9.5 Experiments with High-Level Waste: Methods

According to the preliminary plans (Molecke, 1978b), two classes of experiments will use solidified high-level waste in the WIPP underground workings: studies using "bare" radioactive waste unprotected by a container and studies using full-scale canisters of radioactive waste. The waste will

include fission products and actinide materials fixed in a vitrified, low-leachability matrix as well as in spent-fuel pellets; the containers will include canisters from prototype reprocessing operations and perhaps unreprocessed spent fuel.

In both classes of experiments the underground emplacement of high-level waste and the subsequent sampling will follow strictly prescribed procedures. The experiments will not be routine operations. Detailed analysis will precede each experiment in order to insure its safety; this planning will include analyses of accidents that might occur during the experiment. Written operating procedures will specify each step in each experiment, the apparatus to be used, methods for dealing with events that might threaten to release radioactivity during the operation, and methods for retrieving radioactive material after the conclusion of the experiments.

Experiments with bare waste

This work will study the processes that may occur after corrosion and disintegration of containers have exposed radioactive waste material to salt and brine. It will extend results obtained earlier in the laboratory and determine their applicability to an actual repository. Designed primarily to study chemical, rather than structural or thermal, effects, the bare-waste experiments will investigate degradation of the matrix that encapsulates the waste, leaching of waste materials, and migration of radionuclides. Their design will represent realistic but adverse conditions that may appear in a bedded-salt repository long after the waste is emplaced. These simulated conditions will represent the following chain of hypothetical long-term events: the metallic waste canister has completely disintegrated, yielding corrosion products and bare waste; the waste matrix has partially disintegrated into lumps or into particles the size of sand grains; brine or water vapor has collected in the waste-emplacement hole; and water is leaching the waste.

The experiments will be performed in "reaction chambers," unlined holes drilled into the salt of the WIPP mine. Bare waste will be put into these chambers; other materials, including brine and corrosion products, may be added to simulate various stages of advanced aging. Each chamber will be sampled periodically; the solid, liquid, and gaseous samples will then be packaged and shipped to a laboratory for analysis.

Bare-waste tests that include all possible variations of conditions and replicates needed for statistical accuracy would require an extensive array of reaction chambers. The preliminary planning has established only tentatively the number of chambers and the geometrical design of their emplacement; the number of chambers is currently estimated to be between 20 and 200. The results of laboratory studies will heavily influence the plans for in-situ experiments, for they will point out which areas of interest are the most important for further study underground.

Experiments with full-size canisters

Testing full-size canisters under the actual conditions of a repository will eliminate the uncertainties introduced by extrapolating data from small-scale laboratory tests. It will permit the development of procedures and equipment for handling and retrieving waste in future repositories.

These canisters will be placed in holes drilled in the floors of special underground experimental areas. The holes will then be plugged and perhaps grouted in order to duplicate and test the procedures that may be adopted for use in a repository. After emplacement the canisters will be periodically sampled, presumably by coring through adjacent salt to obtain specimens for laboratory analysis.

Preliminary designs for the experiments with canisters are not complete. The number of canisters required for the studies will probably be between 20 and 200, but these numbers, like the estimates of bare-waste reaction chambers, may change by as much as a factor of 2.

8.10 DEMONSTRATION OF SPENT-FUEL DISPOSAL (ISF)

In accordance with the recommendations of the Interagency Review Group regarding the construction of intermediate-scale facilities (IRG, 1979, p. 59), the WIPP reference mission includes a moderate-scale demonstration of the capability for ultimate disposal of spent fuel in salt. In parallel with the demonstration, experiments with spent fuel under more extreme conditions will also be carried out (Section 8.9). Additional guidelines for the demonstration are that it should be large enough to be meaningful (up to 1000 spent-fuel assemblies could be used), that the heat loading (heat generation per acre) should be lower than the loading that may ultimately be reached in an operating repository, that the spent fuel should be recoverable for a 20-year period, and that the demonstration should be monitored.

8.10.1 Size of the Demonstration

The number of spent-fuel assemblies required for a meaningful demonstration is affected by logistics, heat transfer, the size of the nuclear fuel cycle, and retrievability.

The logistical concerns include obtaining, canistering, transporting, and emplacing the spent-fuel assemblies in the salt. The quantity emplaced must be sufficient to demonstrate the capability of the logistical system and to permit the observation of adverse synergistic effects, if any occur. The annual discharge of a pressurized-water reactor (64 assemblies) would fill a typical disposal chamber in a spent-fuel repository. Using 64 assemblies, the demonstration could include all phases of repository operations: mining the chamber, emplacing the fuel canisters, establishing the required monitor systems, sealing the storage room, and withdrawing from the area. Fewer than 50 to 60 assemblies would probably not provide a sufficient test of these logistical capabilities.

Instruments will monitor the effects exerted on the salt by the heat from the spent-fuel assemblies. For the initial studies, an area with four storage rooms (each with approximately 15 assemblies) and three intermediate drifts would be needed to insure that there is a sufficient buffer around the center of the study area to reduce end effects. Thus, the minimum number of

assemblies required to determine the local effects of heat transfer would be approximately 60 assemblies. To determine far-field effects would require a larger number of assemblies.

The remaining two factors--size of the fuel cycle and retrievability--essentially offset each other. A meaningful demonstration must be significant in comparison with the annual output of all U.S. reactors. The upper limit of 1000 spent-fuel assemblies (the annual output of approximately 15 reactors) would certainly achieve this goal. However, retrievability considerations dictate a cautious approach at first. The description of the demonstration area that follows shows a capability for ultimately handling the upper limit of 1000 assemblies. The initial emplacement will probably be on the order of several hundred to allow collection of short-term data. After this initial information has been evaluated, the total number of assemblies to be emplaced can be decided.

8.10.2 Description of the Storage Area

Present plans are to receive bare or thinly clad fuel assemblies at the plant in existing spent-fuel shipping casks. The assemblies will then be sealed inside canisters before emplacement in the storage area.

The proposed canister for the spent-fuel assemblies consists of a single overpack fabricated from 14-inch-diameter schedule-10 carbon-steel pipe. All fabrication operations except for the final seal weld would be made at an approved commercial fabrication facility. The final seal weld would be made within the WIPP hot cell by remote-welding equipment.

Figure 8-11 shows the conceptual layout of the storage horizon for remotely handled waste. The area for emplacement of spent fuel contains 28 storage rooms, each 14 feet wide, 24 feet high, and 500 feet long. The rooms are spaced on 70-foot centerlines with a resulting extraction ratio of 20%. The emplacement area will be connected to the shaft-pillar complex by four access drifts, which provide paths for ventilation as well as access for mining equipment, storage equipment, and the salt-handling system. The air-supply system for the construction operation will be separated from the storage air system to permit simultaneous mining and storage. Sufficient air quantities will be provided to support the mining and storage operations as well as to remove fission gases that might escape from unsealed storage rooms.

The proposed storage configuration will produce a thermal loading of approximately 30 kilowatts per acre. This value, about one-half the loading that has been suggested for a spent-fuel repository in salt, was chosen to satisfy the guideline that the loading be technically conservative.

Each canistered spent-fuel assembly will be stored in a sleeved hole approximately 25 feet deep; the holes will be spaced on 12-foot centers in the storage drift. Although the thickness of the sleeve has not been determined, it will be sufficient to provide structural integrity for the retrievability period. A shield plug will be placed over the spent-fuel canister in the top 10 feet of the hole.

8.10.3 Retrieval of Spent-Fuel Assemblies

It is not intended to retrieve all of the spent-fuel canisters at the conclusion of the 20-year demonstration. Instead, the spent fuel will probably be allowed to remain in place. All of the spent-fuel assemblies will be retrieved only if analysis of the demonstration or the experimental program shows that retrieval is necessary. A small fraction of the spent-fuel assemblies will be retrieved to ascertain that retrieval is possible and to obtain samples for inspection and analysis; the retrieval will be performed first at short intervals and then at longer ones. Data from the monitoring and inspections will help to evaluate the adequacy of the retrieval schedule.

The retrieval operation in rooms that have not been backfilled will be essentially a reversal of the emplacement operation. In a backfilled drift the retrieval operation will also involve remining the partially consolidated crushed salt filling the drift.

During the early stages of the demonstration, backfilling will not be done. After it has been established that retrieval can be accomplished in the open storage rooms, a limited number of assemblies will be stored in a backfilled configuration. Subsequent retrieval demonstrations will be executed to verify the adequacy of retrieval plans before large-scale backfilling operations begin.

The backfilling of the storage drifts will not greatly affect the results of the demonstration or monitoring program. Therefore, it may be possible to delay backfilling of a major section of the demonstration area until after retrieval has been shown to be no longer necessary. This delay will reduce the costs and time entailed in a full-scale retrieval operation without reducing the amount of information gained from the program.

8.10.4 Monitoring Program

Since the spent-fuel assemblies will be canistered, emplaced in sleeved holes, and stored at a conservative thermal-power density, the reactions that will occur between them and the salt are limited. Nonetheless, an extensive monitoring program will be undertaken to verify that the behavior follows predictions.

It is not expected that waste-salt interactions, waste leaching, or radionuclide migration will occur in the spent-fuel area. Observations on these phenomena will be made within the experimental area (Section 8.9). Canisters recovered in the retrieval operations will be inspected and analyzed to verify that these expectations are correct.

As described in the following paragraphs, measurements and data collection will study the thermophysical response of the salt formation, movements of the canisters and sleeves, release of fission gases, materials integrity, brine migration, and the validity of mathematical models.

Arrays of thermocouples and extensometers will monitor the effects of the low-level heat source; they will obtain creep data and measure second-order

effects such as transfer of radiation energy to the salt. The creep measurements will also determine any movement of the sleeves and canisters. Data on high heat loadings will be obtained from the experimental area.

Monitoring for fission-gas release will be conducted in the storage areas (both backfilled and open) during storage and retrieval operations. This program will sample the air in the tunnel and inside some canisters.

The performance of materials in canisters, sleeves, and fuel assemblies will be observed after retrieval operations, although significant corrosion effects will probably be minimal or nonexistent.

Although brine-migration measurements will be made, a significant influx of brine is not anticipated, because of the low thermal gradients from spent fuel at 600 watts per assembly. Measurements will, however, be made in order to verify this prediction.

Information from all aspects of the demonstration will be used to validate models that predict short-term and long-term repository behavior.

8.11 PLANS FOR RETRIEVAL

An important part of the WIPP project is the ability to remove emplaced wastes from the salt if retrieval becomes necessary or desirable in the future. This section describes retrieval plans, which will be carried out only after a suitable planning and training period.

The retrievability period for waste stored in the WIPP reference repository is 10 years for TRU waste and 20 years for spent fuel. To permit access for retrievability, general undergound storage areas for CH waste will be provided with entryways, and ventilation drifts will be left open. Special equipment, designed for both retrieval and subsequent repackaging, will be shielded to protect the workers.

8.11.1 Retrieval of CH Waste

Contact-handled waste is stored as described in Section 8.4.1. Before decommissioning, CH waste will not normally require backfill; if the waste contains combustible materials, however, a partial backfill of salt may be used to limit the possibility of fire unless other fire-protection methods are judged sufficient.

Retrieval before backfilling

Before salt has been backfilled into the storage rooms, any particular batch of CH waste can be retrieved easily, without the need for moving large quantities of salt. The first step in retrieving CH waste will be to reestablish ventilation through the aisles and the stack of waste by removing the bulkhead at the entrance to the storage room. The containers of waste can

then be removed one at a time in the reverse order of emplacement. Any container found to be breached or externally contaminated will be sealed in another container (overpacked) to prevent the spread of contamination. The containers will be moved to the surface by the same equipment that brought them in.

As retrieval progresses, the floor of the storage room will be checked for contamination and, if necessary, cut away deep enough to reduce the contamination to an acceptable level. The contaminated salt will be packed into drums and moved out with the waste. This cleanup operation might add about 2% to the volume of the waste.

Retrieval after partial backfilling

The waste-storage area will first be cleared of the backfilled salt. Any contaminated salt will be packed into drums and handled like CH waste; it might amount to 25% of the volume of CH waste retrieved. Retrieval will then proceed as though the storage area had not been backfilled.

Retrieval after backfilling

After a decision that retrieval is no longer necessary, the filled storage rooms will be backfilled with crushed salt. After backfilling, the continuing stress-induced creep closure of the room will compress the crushed salt and apply pressure to the waste stack. This closure may possibly damage the waste containers.

Should it be necessary to retrieve some or all of the backfilled CH waste, ventilation will first be reestablished in the particular storage room. Relief saw cuts will then be made in the salt on each side of the waste stack and over its top. The cuts will be as close to the waste stack as possible while insuring that the saw cuts into no waste and that all radioactive material remains inside the salt block outlined by the cuts. The salt between the relief cuts and the waste will be pried or chipped away to free the stack. Any contaminated salt will be placed in sealable containers and handled in the same way as other CH waste. Uncontaminated salt will be moved to the mined-rock pile on the surface. The waste containers will be removed, inspected, sealed in other containers (if necessary), and moved to the surface.

The floor will be decontaminated by mechanically removing the contaminated salt, which will then be placed in sealable containers and hauled away. The volume of salt removed in this operation is expected to equal the volume of waste removed. The fraction of this salt that is contaminated will depend on the mechanical damage to the containers, the corrosion of the containers, the migration of the contaminants, and the care used in retrieval.

8.11.2 Retrieval of RH Waste

The methods for handling and storing RH waste are discussed in Section 8.4. The methods used for their retrieval will depend on whether the operation is performed before or after backfilling.

Retrieval before backfilling

Canisters holding RH waste will be stored in steel-lined holes. The steps used in retrieval will be the reverse of emplacement, with the addition of more-extensive radiation-monitoring equipment and equipment for handling any container breach.

First, the room will be ventilated by properly positioning the air-flow barriers. Owing to the continuing stress-induced creep, the room may need to be remined to the dimensions required for entry of retrieval equipment. Once the location of the canister is determined, a shielded manifold will be grouted into the salt at a known distance above the canister. A hole will be drilled to the top of the canister, and the overcore drill will be driven to about 6 inches below the canister, where an undercut will be made. The canister will then be lifted and sealed into a shielded cask, which will be taken to the surface. The hole will be backfilled with clean salt.

The salt removed during drilling will be caught in a dust collector and sealed in drums. After inspection and inventory, these drums will be handled by the methods described in Section 8.4.1. The volume of such salt is expected to be about twice the volume of the RH waste retrieved.

The salt removed during the remining of the room will be surveyed for contamination. Contaminated salt will be packed into drums and treated as waste; uncontaminated salt will be taken to the mined-rock pile. Little contaminated salt is expected from remining the room.

Retrieval after backfilling

To retrieve RH waste after backfilling, the storage rooms, shafts, drifts, passageways, and ventilation systems will be restored to their original operating conditions. The storage area will then be opened by remotely operated machinery. The volume of salt to be removed is expected to be approximately equal to the amount removed in the original mining of the room. Once the room is opened to the required dimensions, retrieval can proceed in the same way as retrieval before backfilling.

8.11.3 Retrieval of CH and RH Experimental Waste

All wastes used in experiments (Section 8.9) will be removed during the operational phase of the WIPP program. Because these wastes will be in different forms, no single method will govern their retrieval. The plan for each experiment will include a procedure for removing the waste; this procedure will have to be approved by the DOE before the experiment can begin.

8.12 PLANS FOR DECOMMISSIONING

At the end of the WIPP operation, a decommissioning program will be carried out for the safe permanent disposition of both surface and underground facilities. This section discusses the alternatives for decommissioning, the current plan for decommissioning and the ways in which the plant design anti-

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cipates this plan, physical security and surveillance after decommissioning, and current studies of techniques for plugging shafts and boreholes. The environmental effects of decommissioning and dismantling are discussed in Section 9.2.

8.12.1 Decommissioning Alternatives

The alternatives for decommissioning are mothballing, in-place entombment, decontamination and dismantling, and conversion to a new system. These alternatives are discussed in NRC Regulatory Guide 1.86, "Termination of Operating License for Nuclear Reactors." Although there are now no guidelines for decommissioning a waste repository, the purpose of decommissioning is the same for both a waste repository and a nuclear power plant: to protect the health and safety of the public.

These alternatives allow for decommissioning the plant under the following credible situations:

1. Decommissioning after the repository has been filled. The preferred methods would be in-place entombment of unusable underground structures and decontamination and dismantling of the surface structures.

2. Decommissioning after retrieving the waste. The surface and underground would be returned to nearly their original conditions; decontamination and dismantling would be the preferred methods.

3. Decommissioning before the repository is filled, leaving open the possibility of later returning to fill it. Mothballing of the surface and underground structures would be the preferred methods.

The present plan calls for decontaminating and dismantling surface facilities, entombing in the waste-storage area all wastes generated in dismantling the surface facilities, backfilling the mine, and plugging the shafts and boreholes. The actual plan to be used will, however, be chosen at the time of decommissioning; it will insure that the environment and the public are protected.

Mothballing

Mothballing would consist of putting the plant into a state of protective storage for a few decades. This alternative would be selected if later repository operation or experiments were desired. It would require the eventual use of another alternative for permanent disposition of the plant. The plant would be left generally intact except that all radioactive materials would be isolated from the public by suitable barriers and other means to prevent public access to areas with hazardous levels of radiation. Useful equipment could be decontaminated, if necessary, and removed from the site. Adequate radiation monitoring, environmental-surveillance, and security procedures would be established to protect the health and safety of the public. The shafts, mines, and underground facilities would be left intact.

Entombment

Entombment applies mainly to the shafts and mines. Entombment of the surface facilities would be similar to mothballing except that radioactive materials would be removed and placed in the mine or removed from the site. After the removal of usable equipment (and decontamination, if necessary), the mine would be backfilled with salt, and the shafts and boreholes would be plugged. In this alternative the mines and shafts would be permanently sealed; the surface facilities, however, would be available for some other use in the future.

Decontamination and dismantling

Along with decontamination and dismantling of the surface facilities, the shaft and mine would be entombed as described above. Usable equipment would be decontaminated and removed; contaminated equipment and waste would be packaged and either placed in the mine or removed from the site if mine disposal were not feasible. Surface facilities would be demolished and debris removed or buried in the landfill. As nearly as possible, the surface would be returned to its original condition. The present plan for decommissioning, discussed in Section 8.12.2, uses these methods.

Conversion to a new system

It is possible that the plant may be put to another use after repository operations are completed. It cannot now be predicted whether the plant will be converted to another use, but since a railroad spur, roads, and utilities will be available, the site might be used for industrial purposes.

8.12.2 Present Plans for Decommissioning

Present plans call for decontaminating and dismantling the surface facilities and entombing the mines and shafts. All usable equipment and materials will be decontaminated as necessary and removed from the site. Contaminated structural debris and equipment that cannot be decontaminated will be packaged and placed in the mine. Structures will be disassembled after decontamination. Uncontaminated debris and unusable equipment will either be shipped away from the site for disposal or disposed of in the landfill. The evaporation pond will be allowed to decay, then treated like other structures. In the mine, all equipment will be moved to the surface, decontaminated if necessary, and either shipped away from the site if usable or handled like unusable debris from the surface facilities. The mine will then be backfilled with salt from the mined-rock pile. The salt will be dried and compacted as closely as possible to its original density. Shafts will be plugged in accordance with acceptable borehole-plugging techniques (Section 8.12.4).

After these operations, the surface will be regraded to approximate its original contours and seeded. Markers will be provided for shaft locations and the landfill. If any of the mined-rock pile remains, it will be removed. Electrical-power and telephone lines, railroad spurs, and roads may be removed, depending on the future use of the site. If they are removed,

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the rights-of-way will be regraded to approximately their original contours. Water will be shut off at the original connection point; however, water lines will be removed only where not otherwise needed and where necessary to restore the natural terrain.

Many aspects of the plant design are intended to facilitate decommissioning. They include

1. Easy access to material and equipment that may eventually be recovered or dismantled.

2. Smoothing the surfaces of equipment to make decontamination easier.

3. Minimizing small dirt-catching spaces and corners to the prevent the accumulation of radioactivity.

4. Modular construction for ease of dismantling.

5. Use of materials that tend not to become contaminated.

6. Use of equipment that can be disassembled without cutting.

7. Minimizing the weight of blocks of material that will be moved.

8. To the extent possible, use of standard equipment that can be used in other applications.

8.12.3 Post-Decommissioning Controls

The extent of post-decommissioning controls will depend on whether wastes are permanently stored or retrieved (Section 8.11). If wastes are permanently stored and the repository is decommissioned as presently planned, administrative controls will be established to prevent deep drilling, mining, or other activities that might allow water intrusion into the storage area. If surface facilities are not dismantled, fences and other security measures (like sealed doors and periodic inspection) will be needed to prevent public access. If wastes are shipped away from the site, the mine backfilled, and surface facilities dismantled, the need for post-decommissioning controls will be essentially eliminated.

8.12.4 Borehole and Shaft Plugging

An essential task during decommissioning any waste repository will be plugging the remaining holes and shafts. Ideally the integrity of the plugs would be equivalent to that of the surrounding rock formations before human intrusion. It should be noted, however, that the long-term consequence analysis (Section 9.5.1) shows that an unplugged hole has but small environmental or safety consequences. While improvement of plugging technology is desirable to provide additional confidence in geologic isolation, it is not absolutely necessary.

The DOE and its predecessors have conducted borehole-plugging research since 1963. The results obtained so far (and those expected in the near future, including demonstrations of techniques) give the DOE confidence that newly developed plugging methods will be available well before they are needed in decommissioning the repository.

The purpose of the borehole-plugging studies associated with the WIPP project has been to develop and test materials and methods for plugging holes and shafts in rocks and salt at the site. The plugs are to have long-term durability, low water permeability, resistance to groundwater attack, and physical and chemical compatibility with the surrounding rock. The plug materials are also required to bond to the surrounding rock, to expand to fill interstices, to be able to be handled in the field, and to be subject to quality controls that assure conformance with performance specifications. In addition to the DOE studies, Sandia Laboratories has carried out field tests near the site and tests in the laboratory. A more comprehensive program is currently being formulated under a quality-assurance framework appropriate to licensing requirements.

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9 Analysis of Environmental Impacts at the Reference Site

This chapter discusses the environmental impacts of building and operating the WIPP reference repository, of preparing waste for shipment to it, and of leaving waste permanently buried in its underground disposal areas. Some of the conceivable impacts are certain to occur, others are unlikely, and still others are not expected to occur at all. Section 9.1 describes the effects of preparing the site and constructing the plant itself. Section 9.2 describes the effects of normal plant operation and of closing the plant. Section 9.3 analyzes the effects of possible accidents at the plant. Covering both the construction and the operation phases, Section 9.4 analyzes the impacts on the social and economic structure of the two-county area around the plant. Section 9.5 describes effects that may be exerted after the plant ceases operations; it considers, among other effects, the consequences of hypothetical releases of radioactive material from the sealed repository. Section 9.6 discusses the impacts of removing TRU waste from its present storage at the Idaho National Engineering Laboratory and of preparing it for shipment to the WIPP. The last section, 9.7, covers the impacts of leaving the waste in Idaho for the indefinite future.

9.1 EFFECTS DURING SITE PREPARATION AND CONSTRUCTION

The preparation of the site and the construction of both surface and underground facilities will affect the environment. This discussion examines the impacts of those activities. The first and second sections principally discuss impacts that are similar to those of most large construction projects. The next two sections examine separately two of the more important impacts of construction: the effects of piled rock materials brought to the surface during mining and the denial of access to mineral resources beneath the site. A final section reviews plans for mitigating the impacts.

9.1.1 Site Preparation and Construction

The effects of site preparation and facility construction will result from activities such as clearing rights-of-way, excavating large volumes of soil, storing materials in outdoor holding areas, building temporary access roads, setting up temporary structures, and disposing of solid and liquid wastes. Construction schedules--including the timing of activities, the scheduling of machinery use or working hours, and the duration of construction activities--will affect the magnitude of the impacts.

During the 4 years of construction, the level of activity will vary with time and from place to place. It is expected that most of the adverse impacts of construction will begin to occur within the first 2 years.

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9.1.1.1 Land Use

Site preparation and the construction of surface facilities will modify the existing terrain. The modifications will, in turn, affect the use of the land by wildlife or by man. Lands to be preempted by construction are the following:

1. Control zone I: an area of about 50 acres, a small portion of which will be occupied by the surface structures. This entire zone will be cleared of surface vegetation, and the cattle grazing currently taking place on this acreage will no longer be permitted.

2. Mined-rock-storage area: an area of about 30 acres that will be used for storing rock, principally salt, excavated in mining. The present grazing use for these 30 acres will be preempted.

3. Parking lot: approximately 10 acres in control zone II used for automobile parking and removed from grazing for the life of the repository.

4. Spoils-storage area: 50 acres in control zone II used for the temporary storage of earth removed during site leveling. This land will be removed from grazing during the construction period but will afterward be allowed to revert to its natural state.

5. Landfill area: 5 acres in control zone II used for sanitary landfill and removed from grazing for the life of the repository.

6. Biological and meteorological plots: about 50 acres used for biological study plots and the meteorology station. This land will be removed from grazing for the life of the repository.

7. Rights-of-way: 790 acres used as shown in Table 9-1.

Land used for road and railroad rights-of-way will suffer long-term disruption of its natural productivity for grazing, wildlife production, and related uses. Rights-of-way for the electrical-power and water lines will be

Table 9-1. Land Areas Used for Rights-of-Way

Right-of-way	Dimensions		Area (acres)		
	Length (miles)	Width (feet)	Outside zone IV	Inside zone IV	Total
North road	13	200	245	70	315
South road	4	200	25	70	95
Railroad	6	100	35	35	70
Electric line	10	75	65	25	90
Water line	18	100	220	0	220
Subtotal:					
Permanent disruption			305	175	480
Temporary disruption			285	25	310
TOTAL			590	200	790

available for grazing and related uses except during the construction and reclamation periods. The reduction in grazing range will affect only a small number of cattle, probably less than 20 head.

Part of the area occupied by the reference site will be removed from use for recreation. On the other hand, the new road will make the rest of the land more accessible for recreation. The recreational use of the area is mostly hunting for quail, dove, rabbit, and coyote.

Various social and economic impacts related to land use will occur during site preparation and plant construction. These impacts are discussed in Section 9.4.

9.1.1.2 Terrain and Soil

Impacts on the terrain will be minimal since the reference site is level to gently sloping (2% slope). The greatest change in the terrain will result from the disposal of mined material (Section 9.1.3).

The removal of surface soil and vegetation for the construction of pads and access roads will expose the unprotected area to winds and rain. Mine development and mining could cause similar adverse impacts; the impacts of the mined-rock pile are discussed in Section 9.1.3. The construction of buildings will affect the soil in control zone I and in a small part of control zone II.

Additional impacts on soils will occur when roads, railroads, and other service corridors are built. The loss of protective vegetation will induce increased erosion and subsequent soil loss. The impacts on soil in control zone I will last for the life of the repository. Impacts from water lines and electrical-power lines will, however, be brief because, once construction is complete, the soil will recover.

9.1.1.3 Noise

Construction will occur in three phases: site clearing and excavation, building erection, and shaft sinking. Although these phases will overlap, this distinction is convenient for assessing the impact of construction noise because each phase is different acoustically. Site clearing and excavation normally produce the highest noise levels.

Site clearing and excavation

In analyzing the noise produced in site clearing and excavation, it was assumed that the site will be leveled to a base elevation of 3414 feet. Working only one daytime work shift each day, the construction equipment listed in Table 9-2 will be needed. This table also lists the resulting probable sound-pressure levels (SPL) per unit measured at 50 feet for equipment idling and running at maximum load. It is assumed that no blasting will be required.

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Excess material excavated in construction will be placed in a spoils area immediately to the southwest of the plant. Table 9-3 lists the equipment assumed to be deployed at the spoils area.

Table 9-2. Construction Equipment and Sound-Pressure Levels

Equipment	Number of units	Single-unit SPL at 50 feet (dBA)	
		Idle	Maximum
Front-end loader	1	75	90
Bulldozer with a ripper	2	75	90
Bulldozer	4	70	88
Scraper	10	70	86
Grader	1	74	89
Compactor	4	75	90
Flatbed truck	2	70	86
Cherry picker	1	65	81

Table 9-3. Assumed Equipment and Sound-Pressure Levels at the Spoils Area

Equipment	Number of units	Single-unit SPL at 50 feet (dBA)	
		Idle	Maximum
Grader	2	74	89
Compactor	2	75	90
Bulldozer	2	70	88

It is also assumed that (a) all the equipment at the plant site and at the spoils area is to be operated at the maximum sound-pressure level 80% of the time and (b) the equipment is to be evenly deployed over both sites.

These data and assumptions were used to predict probable sound-energy averages (L_{eq}) for site clearing and excavation. At a point 400 feet north of the waste-handling building, the L_{eq} will typically range from 80 to 90 dBA. Further from the site, the noise level will be reduced by spherical divergence and by air and ground attenuation. One mile from the site, the probable L_{eq} will be about 58 dBA. At the nearest residence, the James Ranch, 3 miles to the south-southwest of the site, the expected noise level will probably be about 45 dBA.

The normal ambient noise level in the vicinity of the site has been measured as 26 to 28 dBA. One mile from the site, the construction noises will be clearly discernible above this background.

Building erection

Building-erection noise tends to be broad based and continuous. It results from working with steel for building frames, concrete pouring, crane operation, and diesel trucks. The noise will be similar to that for site clearing and excavation, with occasional sporadic impulsive noise, such as that made by impact wrenches. Overall, the noise level for building erection will be about 5 to 7 dBA lower than that for site clearing.

Shaft sinking

Excavation of the various underground areas will take place throughout the construction period. The noisiest part of the drilling operation will be within the first 50 to 90 feet of drilling. Below this depth, the sound of the power source for the drill begins to drown out the sound of the drill biting through the earth and rock. The noise contribution of the drill power source will mingle with that of the other construction equipment and will not be discernible at the work-site boundary.

Some blasting is expected in shaft excavation. Offsite noise from the blasting will be most intense within the first 50 to 90 feet of excavation. While this intermittent noise will occur throughout the shaft-construction period, the off-site intensity will decrease as the shaft goes deeper.

Other construction activities

When site clearing and excavation are started, work will begin on access roads, the railroad spur, and utility rights-of-way, contributing to the noise along construction routes. The typical L_{eq} for these types of construction activities will range from 84 to 88 dBA at 50 feet. One mile from the site, the L_{eq} will be 45 dBA.

Traffic

The peak commuting traffic along roads to the site may increase by roughly 800 cars per hour during commuting periods. The noise level may then reach an L_{eq} of about 65 dBA at 100 feet from the road.

As construction materials are brought to the site, regular traffic along U.S. 180 will also increase. Each passing diesel truck will produce a momentary sound peak of about 84 dBA measured 50 feet from the road.

The increased traffic is not expected to cause any major noise impact at the ranches along the roads since all increases in traffic will occur during daytime hours. Furthermore, most of the residences are set well back from the road, away from road-noise sources.

Noise standards

At present, there are no Federal or New Mexico State standards for community exposure to noise. The U.S. Environmental Protection Agency (EPA), however, has issued some source-related guidelines for noise emissions from construction equipment. Their objective is to protect workers as well as to reduce undue noise. Most vendors of construction equipment offer quiet machines that meet the EPA guidelines.

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9.1.1.4 Air Quality

The construction of the repository will have an adverse effect on local air quality, but the construction-related emissions of air pollutants and dust will be brief. It is expected that most of the increases in air pollutants and dust emissions will occur during the early stages of construction.

Heavy-duty diesel-powered construction equipment emits carbon monoxide, hydrocarbons, nitrogen oxides, aldehydes, sulfur oxides, and particulates. Fugitive dust (i.e., dust from nonpoint sources) will also be produced during construction. To estimate the annual quantities of these pollutants, it is necessary to know (a) the type and quantity of equipment that will be used, (b) the annual number of hours of operation, and (c) the rate at which the pollutants are emitted. Although an exact description of the construction equipment is not available, a reasonable estimate of the type and the quantity of equipment can be made by using previous large excavations and mining projects as guides. Guidelines dealing with these three factors have been compiled and published by the EPA (1977). An estimate of the equipment inventory and the annual number of hours of operation is shown in Table 9-4.

Table 9-4. Estimated Equipment Inventory for Construction

Category	Annual operation		
	Quantity	Hours per unit	Hours per year
Tracklaying tractors	6	1050	6,300
Tracklaying loaders	6	1100	6,600
Motor graders	4	830	3,320
Off-highway trucks	16	2000	32,000
Miscellaneous	10	1000	10,000

From these figures it is possible to calculate the total annual air-pollutant emissions by applying the EPA emission factors for heavy-duty diesel-powered construction equipment. The emission factors are listed in Table 9-5, and the calculated annual emissions are presented in Table 9-6. The nitrogen oxides emitted during construction (140 tons per year) can be compared with the present emissions in Eddy County, New Mexico, estimated by the New Mexico Environmental Improvement Division to be 5445 tons per year. The environmental impact of these emissions on the surrounding area will be negligible in comparison.

Fugitive dust will probably be the most common air pollutant during the construction of the repository. It will be produced by the pulverization and abrasion of surface materials and the entrainment of dust particles in turbulent air currents or in high winds (EPA, 1975). The frequency and the intensity of these two phenomena can be described in terms of six parameters: soil type, wind speed, surface moisture, precipitation, vegetative cover, and traffic.

Table 9-5. Emission Factors for the Construction Equipment Listed in Table 9-4

Pollutant	Emission factor (lb/hr)				
	Tractors	Loaders	Graders	Trucks	Misc.
Carbon monoxide	0.386	0.160	0.215	1.34	0.414
Exhaust hydrocarbons	0.110	0.032	0.054	0.437	0.157
Nitrogen oxides	1.47	0.584	1.05	7.63	2.27
Aldehydes	0.027	0.009	0.012	0.112	0.031
Sulfur oxides	0.137	0.076	0.086	0.454	0.143
Particulates	0.112	0.058	0.061	0.257	0.139

Table 9-6. Annual Source Strength from the Construction Equipment Listed in Table 9-4

Pollutant	Source strength (lb)					
	Tractors	Loaders	Graders	Trucks	Misc.	Total
Carbon monoxide	2432	1056	714	42,800	4,140	51,222
Exhaust hydrocarbons	693	211	179	13,984	1,570	16,637
Nitrogen oxides	9261	3854	3846	244,160	22,700	283,461
Aldehydes	170	59	40	3,584	310	4,163
Sulfur oxides	863	502	286	14,528	1,430	17,609
Particulates	706	383	203	8,192	1,390	10,874

The soil at the site is mainly a deep fine sand that is highly susceptible to wind erosion and dust production. The mean wind speed varies from about 8 mph in autumn to about 11 mph in spring. Since the spring is relatively dry and is also the windiest season, the potential for natural dust storms is greatest during this time. However, since the region receives an average annual rainfall of only 13 inches, the potential for airborne dust exists throughout the year.

Vegetation tends to modify the undesirable dust-producing characteristics of sandy soils, high wind speeds, and low precipitation: it cuts down wind speeds near the surface; its roots act as a soil binder; and it tends to retain the water that might otherwise run off. In general, the vegetation at the site is sparse, consisting primarily of woody plants, with small patches of short-statured perennial and annual grasses (Appendix H).

Fugitive-dust emissions can be estimated by using the EPA emission factor for heavy-construction operations--1.2 tons per acre per month of construction. Most of the construction will occur in control zone I. To assess the

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ground-level dust concentration at the site boundaries, the Pasquill-Gifford diffusion equation may be employed (Turner, 1969; PEDCo, 1973):

$$\chi = \frac{0.36Q}{\pi u \sigma_y \sigma_z}$$

where

χ = 24-hour ground-level concentration (in grams per cubic meter) at the desired location

Q = continuous emission rate (in grams per second) from a ground-level source

σ_y = a horizontal dispersion coefficient (in meters) that depends on atmospheric stability and downwind distance from the source

σ_z = a vertical dispersion coefficient (in meters) that depends on atmospheric stability and downwind distance from the source

u = mean wind speed (in meters per second)

The quantity Q is estimated to be 120 tons per month for a 100-acre construction site, or 172 g/sec during normal working hours (22 days per month, 8 hours per day). The average value of Q over a 24-hour period is thus 57 g/sec. Two miles downwind from the construction site, the product of the dispersion coefficients σ_y and σ_z is 17,000 square meters under restrictive dispersion conditions (Turner, 1969, p. 53). The mean wind speed of 7 mph was obtained from preliminary meteorological data for the site.

With these values, the dispersion equation predicts that during normal working hours the ground-level dust concentration might reach 0.37 mg/m^3 at a distance of 2 miles downwind from the construction site. The 24-hour average concentration would then be 0.12 mg/m^3; the 24-hour quality standard for airborne particulates in ambient air is 0.15 mg/m^3. Therefore, if no mitigating measures were applied, fugitive-dust emissions from construction activities might be close to Federal or State standards for suspended particulates during times when the restrictive assumptions on dispersion coefficients are valid.

A greater problem during construction will be the generation of large quantities of fugitive dust by construction vehicles. Mitigating measures may include paving, graveling, wetting, or other palliative treatment of construction roads; restricting off-road travel as much as possible; wetting vehicle loads; and removing load spills and wheel mud from roads as quickly as possible. Such a control program can reduce fugitive dust from construction activities by 50 to 75% (EPA, 1977).

To control gaseous and particulate emissions from diesel equipment, pollution-control devices can be installed on all diesel-powered construction equipment. These devices may reduce particulate emissions by approximately 75% and gaseous emissions by 50 to 75%.

9.1.1.5 Biological Resources

Adverse impacts on biological resources are expected to be slight for the following reasons (Appendix H):

1. No proposed natural areas are present on or near the site.

2. No endangered species of plants or animals are known to inhabit the site or the vicinity of the site.

3. Water requirements for the site are low.

4. The land contains soil types and vegetation associations that are common throughout the region of the site.

5. Access in the form of dirt roads is already available throughout the area; therefore, recreational use of the area is not likely to increase significantly.

Planned mitigation measures will prevent unnecessary damage to plants and animals in areas that might be affected by fugitive dust (Section 9.1.1.4) and dispersed salt (Section 9.1.3). Other biological effects of construction will result from the removal of land from rangeland habitats; the acreages to be removed are listed in Section 9.1.1.1.

A number of impacts may be expected from the construction of rights-of-way. Some raptor deaths may be caused by electrocution on utility lines. Although some negative effects (increased animal mortality, inhibition of animal movements) should be expected when the roads are built, roadways often have a positive effect on local biota by increasing the diversity of habitats. Creosotebush may invade and thrive along the roadway and railroad, providing cover within these corridors. As explained in Section 9.1.1.1, much of the land cleared during construction will revert to natural vegetation. Although some of the removed plant species may remain absent from the rights-of-way for years, the impact is considered minor because the removed species are very common in the region.

Right-of-way construction will frighten and displace the wildlife inhabitants. This disturbance is attributed not only to habitat removal but also to an increase in the visibility of people and frequent sharp increases in ambient noise levels. The displaced species will migrate to adjacent undisturbed habitats and may temporarily cause an ecological imbalance or stress condition in local adjacent habitats, resulting in a loss of most of the displaced organisms. However, the positive effect of right-of-way corridors on bird populations has been documented (Anderson, Mann, and Shugart, 1977). The effect has been to increase habitat diversity (the "edge effect") and, in turn, the densities of some bird species. Summer residents have sometimes increased in density at the apparent expense of year-round residents.

The environmental impact of corridors has been studied by ecologists for a relatively short time, and concepts are still in the formative stages. Corridors provide habitat that may favor the establishment of small-mammal communities differing in composition from surrounding communities. Animals adapted to open areas may appear in the new communities, and transient species may be

able to outcompete residents. In general, however, the width of corridors will be minimized, and as much vegetation cover (nongrass) as possible will be allowed. Considering the extent of existing corridors, those associated with construction are of little consequence.

As construction activities begin in control zone I, more animals will be displaced by construction noise. The construction of surface facilities will require the destruction of some shinnery oak, sagebrush, mesquite, grass, and yucca. The removal or displacement of this vegetation and the fauna it supports may be considered a minor impact because these habitats contain species common throughout the region.

9.1.1.6 Archaeological Resources

As stated in Section 7.4, there are no known historical or natural landmarks within the reference site, although the archaeological sites as a whole have been nominated as an archaeological district (Appendix I). Data from the archaeological field survey indicate that, statistically, the site contains about eight archaeological sites per square mile. Thus there are potentially 240 sites within the boundaries of the site, with an additional 7 sites within the proposed rights-of-way outside the site. As many as twelve of these potential 247 archaeological sites could be disturbed and lost during construction; two of these would be within control zone I and under the preempted areas of control zone II and ten would be within the rights-of-way.

Improved access to the area of the site may have an indirect effect on the archaeological resources of the region. An increase in the number and type of roads in a previously inaccessible area frequently increases the use of the area for recreation, particularly on weekends and holidays. With new access roads leading into the area, an increase in the number of amateur pot hunters and a consequent increase in the disturbance of archaeological sites can be expected.

Mitigating actions will be taken before and during construction to prevent the loss of the 12 archaeological sites that might be in the path of ground-clearing activities in control zones I and II and in the proposed rights-of-way. Archaeologists will be consulted on how to avoid sites or to recover their values if they cannot be avoided.

9.1.1.7 Unusual Geologic Resources

The mineral langbeinite is the only unusual geologic resource at the site. Should mining of langbeinite in control zones I, II, and III be prevented, these deposits will remain in their natural state. Section 9.1.4 discusses the denial of this resource and the economic significance of the denial. No adverse impacts on other unusual geologic resources are expected because no other existing or potential unusual geologic resources have been identified within the area of the site.

Any fossils found in the lifeless rocks at the site would be rare but of great interest. For example, in Texas, fossils have been reported in the

lower part of the Rustler Formation. The fauna, consisting of 35 species of mollusks that lived in abnormally saline water, is thought to be the youngest of Permian age so far found in North America (Walter, 1953). Exploration and construction activities that might discover or expose any fossils would therefore have a beneficial impact. Similarly, exploratory drilling and the construction of mine shafts and waste-storage chambers might provide unique exposures of rock in areas on which subsurface information is sparse. Therefore, stratigraphic, lithologic, mineralogic, and structural information gained from exploration and construction at the WIPP reference site might be of scientific research value and of considerable benefit to the scientific and industrial communities.

9.1.2 Resources Used

The resources committed in site preparation and repository construction consist of (a) land temporarily disturbed as well as land occupied by the pilot plant, (b) natural resources such as fuels or nonrecyclable building materials, and (c) terrestrial biota destroyed or displaced from the site. In addition, the construction may foreclose alternative uses of the land or resources for the life of the project. However, as stated in Section 9.1.1, construction traffic will be restricted to roads, and landscaping will restore the site to as nearly its original condition as possible. This section discusses and, where possible, quantifies the irreversible and irretrievable commitments of resources for the reference repository.

9.1.2.1 Water Consumed

According to current estimates, the reference repository will require 22 million gallons of water during the 4-year construction phase. This water will be purchased from, and delivered by, the Double Eagle System, a part of the Carlsbad municipal water system. The use of this allotment of water by the plant will not preempt existing industrial, agricultural, or municipal uses of water. Although the town of Carlsbad has purchased the rights to this water, it has neither piped it in nor allocated it for municipal or agricultural uses. Moreover, the quantity of water required by the plant (about 17 acre-feet per year) is less than 0.3% of Carlsbad's current withdrawal from the Capitan reef (Appendix H).

9.1.2.2 Building Materials Consumed

The types and estimated quantities of building materials to be used during the construction of the reference repository are given in Table 9-7.

The use of these construction materials for the repository will not significantly affect their availability in the region. Because the quantities of materials required are very low in comparison with the national output, their use for the construction of the repository should not forestall other construction.

Table 9-7. Construction Materials for the Reference Repository

Material	Estimated quantity	1976 U.S. production[a]
Concrete	125,000 bbl portland cement	387 million bbl portland cement
Steel	15,000 tons	127.9 million tons
Copper	150 tons	1.6 million tons
Aluminum	200 tons	6.25 million tons
Lumber	0.5 million board feet	96,905 million board feet
Other materials	No estimate	

[a]Data from the U.S. Department of Commerce (1977).

9.1.2.3 Energy Consumed

The electrical power and the fuels to generate electrical or mechanical power during the construction of the repository are given in Table 9-8.

The electrical power for the construction as well as the operation of the plant will be purchased from the Southwestern Public Service Company (SPSC). The fuel required to produce this power will be only an insignificant addition to the fuel currently used to produce the 750 million kilowatt-hours that SPSC supplies each year to its Carlsbad service area.

The fuels required by the plant and by the labor force for commuting to and from work will probably be purchased from regional sources and retailed by local suppliers.

Table 9-8. Estimated Energy Consumption During Construction

Power source	Approximate quantity
Electricity	
Total, kilowatt-hours	4 million
Peak demand, kilowatt	1700
Normal demand, kilowatts	850
Propane, gallons	140,000
Diesel fuel, gallons	1.5 million
Gasoline, gallons	940,000

9.1.3 Mined-Rock Storage

In the course of site preparation and construction, the underground areas of the reference repository will be excavated by current mining techniques. As a result of this mining activity, approximately 3 million tons of bulk mined salt and other minerals will be stored in an aboveground mined-rock

pile, approximately 80 feet high. The pile will cover about 30 acres in control zone II for the life of the project. All mined salt stored will be less than 2 inches in size, and approximately 50% will be less than 0.5 inch in size. In addition to preempting existing and planned land uses and changing the appearance of the terrain, this method of storing the mined rock may cause salts from the surface of the pile to be dispersed by runoff or by wind erosion.

In this section, some of the discussion of environmental impacts is based on data gathered during field studies around the mined-rock pile at the Gnome site 9 miles from the WIPP reference site. In the Gnome project, carried out in 1961, an underground nuclear explosion took place in cavities that had been mined in the Salado Formation. The pile of mined materials has remained at the Gnome site for 17 years. Although this pile, which covers about 3 acres, is smaller than the WIPP pile will be, it has furnished actual field data that can be scaled to assess impacts at the reference site.

9.1.3.1 Terrain and Soils

The 30 acres of soil covered by the mined-rock pile will be rendered sterile and nonproductive by the stored salt. This impact on the soil beneath the pile will be permanent. Small areas within the ditch around the pile will be affected by the accumulation of high salt levels in the soil--accumulations that result from water runoff.

Some salt will become airborne during transfer from the mine to the pile. The mined rock will be taken by covered conveyor from the head frame to an uncovered stacker conveyor. While on the stacker conveyor, the rock will receive a light water spray to suppress dust; it will then be dumped onto the pile. Although some salt dust will be blown off the conveyor, a larger amount will be blown from the plume of dust and larger particles formed when the rock drops to the pile. Particles smaller than 100 microns in diameter may, depending on wind velocity, be swept completely off the pile; larger particles can be expected to remain in the area surrounded by the ditch. The amount of dust in the plume may be roughly estimated from measurements of particulates produced in potash mining (J. H. Metcalf, Sandia Laboratories, private communication, 1978) and from data gathered in salt-crushing mills; these data suggest that each ton of salt delivered to the pile will produce about 10 grams of dust particles smaller than 125 microns in diameter. This proportion of dust would contribute about 30 tons of salt that the wind could distribute over distances of several miles.

Some material will be blown off the pile; a review of wind-erosion data (EPA, 1977) suggests that 1 to 3 pounds of material per ton of salt delivered might be blown off if the pile were to remain in place for 25 years without forming a crust that would resist erosion. Such an erosion-resistant crust will form on the pile under the influence of rainfall, atmospheric moisture, and moisture in the salt itself. The water sprayed for dust control will hasten the cementing of the surface, and water penetration will produce extensive recrystallization of the salt mass. After stabilization by cementing and recrystallization, the pile will have few particulates available for wind transport. Most of the particulates that are available will be produced by drying after precipitation has dissolved part of the pile surface; in large part, they will be insoluble residues of the mined rock, not salt.

Field examination of the mined-rock pile at the Gnome site (Intera, 1978) supports these expectations. An upper limit to the deposition on the surrounding land is 0.1 pound of salt per ton of mined rock in the pile; because the distribution of this salt around the pile is uniform and shows no correlation with prevailing wind directions, the salt has probably come not from the pile but from other sources in the region, such as Laguna Grande de la Sal or potash tailings piles. Furthermore, measurements of the shape of the Gnome pile show that less than 1 or 2% of it has moved in the 17 years that it has been in place; most of the material that has moved has remained within the berm surrounding the pile. Inspection of the surface and of cores taken from the surface shows that the pile is cemented and that most of the surface particulates freed during cycles of drying and wetting are not salt.

Since the mined-rock pile will probably never contain at any one time the entire 3 million tons of material brought up from underground, even the limited impacts suggested here are greater than those likely to occur. The effects of the pile on the surrounding terrain will not be severe.

9.1.3.2 Land Use

The present grazing use of the entire 30 acres will be preempted for the life of the repository. Recreational uses of this area for hunting quail, dove, rabbit, and coyote will also be foreclosed.

9.1.3.3 Biological Resources

A total of 30 acres of vegetation from the shinnery oak, senecio, sagebrush, yucca, mesquite, and broom snakeweed vegetation types will be cleared for the mined-rock-storage site. All vegetation and wildlife within this area will be permanently removed, and the underlying soil will be sterilized as salt-contaminated water leaches through the rock pile.

Environmental studies conducted around salt-tailings piles at nearby potash mines indicate that vegetation adjacent to these piles will be reduced or eliminated (Appendix H). It is possible that in small areas next to the pile enough material will be deposited to cause adverse effects; it is reasonable to assume that some vegetation may be lost. The field examination around the Gnome mined-rock pile, however, found no identifiable salt-related stress on any of the vegetation in the area with the single exception of a mesquite tree growing on one end of the pile itself (Intera, 1978).

The deposition of 3 million tons of mined salt is insignificant when compared with the 200 million tons of salt tailings, which increase by 14 million tons annually, already deposited by local potash-mining operations.

9.1.3.4 Water Resources

Salt blown from the pile will not reach the local groundwater supplies. Although storm runoff could conceivably carry blown salt to the Pecos River,

14 miles away, this transport mechanism is in actuality not available. Rainwater at the site normally disappears into the ground very quickly; only an occasional severe rainstorm is heavy enough to cause transient surface flow. All such stormwater is caught in low spots and evaporated or absorbed by the sand; there is no drainage developed at Los Medanos that leads to the Pecos. Surface runoff directly from the salt pile will be collected by a drainage ditch, where it will be allowed to evaporate and soak into the ground.

9.1.4 Denial of Mineral Resources

This section describes the economic significance of the specific quantities and grades of potash and hydrocarbon resources beneath the reference site. As discussed in Section 7.2.7, potash and hydrocarbons are the deposits that would be most affected. A more comprehensive discussion of the effects of denying these resources is given in the Geological Characterization Report (Powers et al., 1978, Chapter 8).

It is important to note that the denial of mineral resources is here considered only as it applies to the public, and not to the individual owner or lessee. If the WIPP proceeds at this site, the individual can be compensated for his loss, but the permanent loss to the public of natural mineral resources must be counted among the environmental consequences of land commitment to the repository.

9.1.4.1 Summary

The mineral resources that are expected to underlie the four control zones of the reference site are caliche, gypsum, salt, sylvite, langbeinite, crude oil, natural gas, and distillate (Table 9-9). Potassium salts (sylvite and langbeinite), which occur in strata above the repository salt horizons, and hydrocarbons (crude oil, natural gas, and distillate), which occur in strata below the repository, would be the most affected. The reserves at the site are potash and hydrocarbons (Table 9-10). ("Resources" are minerals that may be of value in the future; "reserves" are the portion of the resources that could be produced at today's market prices and with existing technology.)

The commitment of land to the reference repository will reduce the availability of some potassium salts and hydrocarbons. In order to put the denial of these minerals in perspective, one needs to compare them with regional, national, and world resources and reserves. Table 9-11 contains the elements for such a comparison. The data reveal that, except for langbeinite (for which there are substitutes), the total land commitment has little effect on the regional availability of minerals and almost no national significance. This is true whether the comparison is from the standpoint of resources or reserves.

If at some time in the future drilling and mining are allowed in control zone IV, the impact of withdrawing mineral resources and reserves will be reduced. As shown in detail in Section 9.1.4.7, exploitation of control zone IV would recover a significant fraction of the minerals--73% of the langbeinite reserves, for example.

9.1.4.2 Potash Resources

Langbeinite, a relatively rare evaporite mineral found in commercial quantities only in the Carlsbad area and in eastern Europe, is used chiefly as a fertilizer. It contains soluble potassium, magnesium, and sulfur desirable in certain soils that require such elements but cannot tolerate additional chlorine. Potassium sulfate is equally beneficial to plant growth but lacks soluble magnesium. Immense potassium sulfate resources exist in the Great Salt Lake, Utah, and other brine lakes.

Langbeinite deposits are present in substantial amounts at the reference site, and their extent has been well delineated. Because there is no comparable study of other langbeinite deposits either in the Carlsbad Potash Mining

Table 9-9. Total Mineral Resources at the Reference Site

Resource	Quantity	Depth (ft)	Richness
Caliche[a]	185 million tons	At surface	21-69% insoluble
Gypsum[a]	1.3 billion tons	300-1500	Pure to mixed
Salt[a]	198 billion tons	500-4000	Pure to mixed
Sylvite ore[b]	88.5 million tons	1600	11.8% K_2O
Langbeinite ore[c]	264.8 million tons	1800	6.10% K_2O
Crude oil[d]	37.50 million bbl	4000-20,000	31-46° API[e]
Natural gas[d]	490.12 billion ft^3	4000-20,000	1100 Btu/ft^3
Distillate[d]	5.72 million bbl	4000-20,000	53° API[e]

[a]Data from Siemers et al. (1978).
[b]Equivalent to 10.44 million tons of K_2O. Data from John et al. (1978).
[c]Equivalent to 16.15 million tons of K_2O. Data from John et al. (1978).
[d]Data from Foster (1974).
[e]The degrees API unit has been adopted by the American Petroleum Institute as a measure of the specific gravity of hydrocarbons.

Table 9-10. Total Mineral Reserves at the Reference Site

Reserve	Quantity	Depth (ft)	Richness
Sylvite ore[a]	27.43 million tons	1,600	13.33% K_2O
Langbeinite ore[b]	48.46 million tons	1,800	9.11% K_2O
Natural gas[c]	36.85 billion ft^3	14,000	1100 Btu/ft^3
Distillate[d]	0.55 million bbl	14,000	53° API

[a]The sylvite deposits are equivalent to 3.66 million tons of K_2O; they do not quite meet today's market conditions according to the U.S. Bureau of Mines (USBM, 1977).
[b]Equivalent to 4.41 million tons of K_2O. Data from the U.S. Bureau of Mines (USBM 1977).
[c]Data from Keesey (1976).
[d]Estimated from data presented by Foster (1974).

Table 9-11. Significance of the Resources and Reserves at the Reference Site

Deposit	Reference site	Region	United States	World
		RESOURCES[a]		
Sylvite				
Quantity, million tons K_2O	10.44	500	1000	100,000
Percentage at reference site		2.1	1.0	0.0104
Langbeinite				
Quantity, million tons K_2O	16.15	No estimate available		
Crude oil				
Quantity, million barrels	37.50	1915	200,000	Not available
Percentage at reference site		2.0	0.019	
Natural gas				
Quantity, billion cubic feet	490	25,013	855,000	Not available
Percentage at reference site		2.0	0.057	
Distillate				
Quantity, million barrels	5.72	293	Not available	
Percentage at reference site		2.0		
		RESERVES[b]		
Sylvite[c]				
Quantity, million tons K_2O	3.66	106	206	11,206
Percentage at reference site		3.4	1.8	0.033
Langbeinite				
Quantity, million tons K_2O	4.41	38[d]	38[d]	Not available
Percentage at reference site		11.6	11.6	
Crude oil				
Quantity, million barrels	Nil	471.7	29,486	646,000
Percentage at reference site		0	0	0
Natural gas				
Quantity, billion cubic feet	36.85	3865	208,800	2,520,000
Percentage at reference site		0.95	0.018	0.0015
Distillate				
Quantity, million barrels	0.55	169.1	35,500	Not available
Percentage at reference site		0.32	0.0014	

[a]Data sources: Hydrocarbons, Foster (1974) for the site and region; potash salts, John et al. (1978) for the site and region; Brobst and Pratt (1973) for U.S. oil and gas and the world resources of sylvite.

[b]Data sources: Hydrocarbons, Keesey (1976) for the site; American Petroleum Institute (1978) for the region, the United States, and the world; potash salts, U.S. Bureau of Mines (USBM, 1977).

[c]The U.S. Bureau of Mines (USBM, 1977) does not consider any sylvite to be commercial today. However, one bed (mining unit A-1) of sylvite was marginal and has been added to the reserve list.

[d]Not an official estimate by the U.S. Geological Survey; see Section 9.1.4.

District or in eastern Europe, it is difficult to determine whether the deposits near the site should be considered significant for future needs of chemical fertilizers. However, the total langbeinite reserve at the site is equivalent to only 5 years of production of such ore at Carlsbad.

9.1.4.3 Significance of the Results of Potash-Resource Evaluation

Estimates of the total potash resource are considered to be accurate because of the density of exploratory drilling at the reference site and in adjacent areas. The data base exceeds both in quality and in quantity that available to other investigators who have formulated national or worldwide resource estimates. Additional drilling in the area of the site would enhance the accuracy of the estimate of resources, but no change exceeding a few percent plus or minus is expected.

The definition of reserves is another matter, and drilling may be necessary on centers as close as 1000 feet or less to outline the boundaries of ore bodies that will meet the more rigid modern requirements of assumed economic minability.

It is emphasized that most of the site is underlain by potassium salts classifiable as resources. All but the very center and parts of the southwestern part of the site contain potash resources, when judged by the median standard termed "lease grade" in Table 7-5 (Figure 9-1). The quantity of potassium salts that satisfies these requirements is 264.8 million tons of langbeinite-bearing beds at a K_2O content of 4% or more supplemented by 88.5 million tons of sylvite-bearing beds that contain 10% or more K_2O equivalent. The significance of this mineralization, discovered mostly by the 21 exploratory holes drilled by the DOE, has justified an expansion of the Known Potash District. When the site was first selected in late 1976, the mineralization was thought to lie mostly outside the district but is now known to lie mostly inside.

However, these resources need to be placed in perspective. While the numbers by themselves appear large, they are not when compared with potassium salts available nearby in the Carlsbad Potash Mining District and are even less so when compared with national and worldwide resources. The discussion will commence with sylvite, because it has much less significance in terms of either regional or national resources.

The U.S. Geological Survey (USGS) estimates that the Carlsbad Potash Mining District contains 5000 million tons of potassic salts, mostly sylvite, that meet the lease standard (i.e., contain 10% of K_2O equivalent or better). The reference site contains 88.5 million tons of sylvite-bearing resources, or only 2.09% of the resources available nearby. The potash resources of the entire United States that can meet the 10% K_2O as sylvite requirement are at least twice as large. Hence, the total land commitment for the reference repository results in a denial of about 1% of the national resources of sylvite.

Langbeinite contained within the site is not so easily discounted. Langbeinite is both a rare and a useful evaporitic mineral. Furthermore, Carlsbad

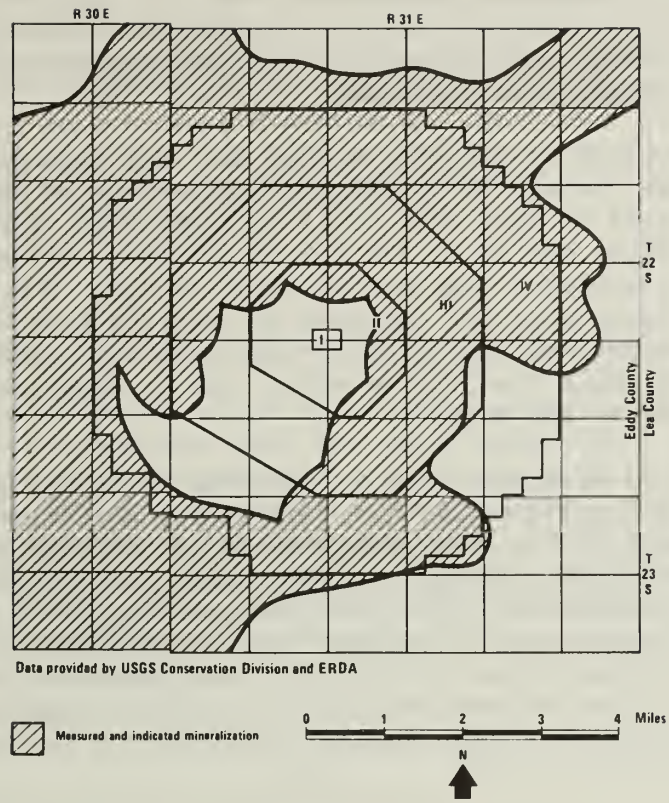

Figure 9-1. Lease-standard potash resource. Measured and indicated mineralization is at a cutoff of 4% K_2O as langbeinite, or 10.0% K_2O as sylvite, or equivalent grade of mixed langbeinite-sylvite occurring in a minimum 4-foot interval.

is the only source of this mineral in the free world. Only two mining companies (International Minerals and Chemical Corporation and Duval Corporation) are presently mining and marketing langbeinite, and no public disclosure of their leased resources has been made, in order to protect their exclusive rights. The USGS has made no definitive study to determine the langbeinite resources in the Carlsbad District. (Langbeinite reserves, however, have been estimated by a private company; see the next section.) The site contains considerable langbeinite resources, 264.8 million tons of 6.10% K_2O equivalent. The grade of langbeinite currently being mined is not known but is estimated to be approximately 8% K_2O equivalent. The USGS estimates that the site contains 79.2 million tons of langbeinite resources of this quality.

No further comparison can be made of langbeinite resources until either the two mining companies elect to release their proprietary information or the USGS conducts an independent study of langbeinite resources that encompasses the entire Carlsbad District. Pending such events, lessening the impact of denial of langbeinite resources known to exist under the site rests with the use of substitutes--a subject addressed in the section that follows.

9.1.4.4 Significance of the Results of the Potash-Reserve Study

Commencing with a resource base of 88.5 million tons of sylvite-bearing mineralization and 264.8 million tons of langbeinite-bearing mineralization, the U.S. Bureau of Mines determined that only 48.46 million tons of the langbeinite can be considered ore today.

If liberal allowance is given to mining unit A-1 (either by improvement in the market price for muriate or by advances in extraction technology), then the resources assigned to that unit could be classed as reserves. The average grade of this potential ore is 13.33% K_2O as sylvite. Therefore, the ore bed within the site contains 3.66 million tons of K_2O. The USBM has estimated that the Carlsbad District contains 106 million tons of K_2O as reserves; the site represents only 3.4% of that reserve. These percentages are considered to be so small that little effect can be expected from denial of the sylvite reserves at the site.

The ores assigned to mining unit B-1 average 9.11% K_2O as langbeinite, resulting in a calculated 4.41 million tons of K_2O equivalent. There has been no USGS estimate of the total reserves of langbeinite in the Carlsbad area. A private consulting company, Agricultural and Industrial Minerals, Inc. (AIM), has estimated that the total resource may be 63 million tons of K_2O equivalent, of which only 38 million tons are classed as reserves; if so, then the entire site contains 11.6% of those reserves. Since Carlsbad is the only district in the United States that produces langbeinite, these figures are significant in terms of land commitment to the reference repository.

While langbeinite is a significant mineral reserve at the site, there are compensating factors. Because the Carlsbad area may contain no more than 38 million tons of K_2O as reserves or 63 million tons of K_2O as resources, the supply is exhaustible. Currently the reserves are depleted by mining at a rate of 900,000 tons of K_2O per year. The projected life of the operations is 42 years if the projection is based on reserves and no more than 70 years if the projection is based on resources. Because Carlsbad is the only known langbeinite district in the United States, it will eventually be necessary to substitute other minerals. Use of the total reserve at the site would forestall this depletion by only 5 years at the most.

Although langbeinite is a desirable plant fertilizer, there are substitutes. Potassium sulfate is the principal beneficial ingredient. For that matter, some langbeinite produced from Carlsbad is transformed into potassium sulfate by a base-exchange process between langbeinite and sylvite:

$$K_2SO_4 \cdot 2MgSO_4 + 4KCl \longrightarrow 3K_2SO_4 + 2MgCl_2$$

Potassium sulfate can also be produced by the Mannheim process, a reaction between sylvite and sulfuric acid:

$$2KCl + H_2SO_4 \longrightarrow K_2SO_4 + 2HCl$$

Potassium sulfate is also present in the brine water of the Great Salt Lake, Utah, and is now being extracted commercially by one company. Brines in Searles Lake, California, also contain commercial quantities. No estimate of the reserves of potassium sulfate contained in these brines has been published, but AIM engineers estimate that these reserves are approximately six times larger than what AIM believes is present in the langbeinite ores at Carlsbad. They also believe that a synthetic langbeinite can be produced by solar evaporation of seawater. It must be admitted that these alternative sources will be somewhat more expensive than conventional mining and refining of natural langbeinite deposits.

9.1.4.5 Significance of the Results of the Hydrocarbon-Resource Evaluation

To put the hydrocarbon resources into perspective, refer to Table 9-11. While quantities of hydrocarbons that may exist under the site are large, they account for only 2.0% of the crude oil, 2.0% of the natural gas, and 2.0% of the distillate of the total such resources that should exist in the region. (The region is here defined as the area studied by the New Mexico Bureau of Mines and Mineral Resources. That area contains 967,700 acres, or 1512 square miles, versus only 18,960 acres, or 29.625 square miles for the site.) On the national basis, the expected crude oil at the site accounts for only 0.019% and natural gas for only 0.057%.

9.1.4.6 Significance of Hydrocarbon Reserves

The estimated hydrocarbon reserves at the site are 36.85 billion cubic feet of natural gas and 0.551 million barrels of distillate. Table 9-11 compares these reserves with similar estimates for the region, the United States, and the world. The natural gas amounts to only 0.95% of the quantity expected in the region (southeastern New Mexico). The distillate is less, 0.32%. On a national level, the percentages reduce to 0.018% for gas and 0.0014% for distillate.

9.1.4.7 Reduction of Impact on Potash and Hydrocarbons by Exploitation of Control Zone IV

To a large extent the mineral deposits at the reference site lie under zone IV, the outer control zone. Mining and drilling may be allowed in this zone if they do not affect the integrity of the site. For example, the hydrocarbons could be recovered by slant drilling: wells located outside control zone IV would start vertically downward through the evaporites and then deviate from the vertical to reach pools under control zone IV. Potash mining may be allowed if sufficient pillars or backfilling would prevent mine subsidence. Future studies will determine what methods may be used in control zone IV.

Table 9-12 gives data showing the reduction in impact if the minerals in control zone IV are exploited. More than half the hydrocarbon resources and

Table 9-12. The Effect of Allowing Exploitation of Hydrocarbons and Potash in Control Zone IV

Deposit	In total site	Remaining in inner zones	Percentage of total potentially recoverable
	RESOURCES		
Sylvite,[a] million tons K_2O	10.44	2.25	78
Langbeinite,[a] million tons K_2O	16.15	5.11	68
Crude oil,[b] million barrels	37.50	16.12	57
Natural gas,[b] billion cubic feet	490	211	57
Distillate,[b] million barrels	5.72	2.46	57
	RESERVES		
Sylvite,[c] million tons K_2O	3.66	Nil	100
Langbeinite,[c] million tons K_2O	4.41	1.21	73
Crude oil, million barrels	--	--	--
Natural gas,[d] billion cubic feet	36.85	23.5	36
Distillate, million barrels	0.55	0.35	36

[a]Data from John et al. (1978, Table 4).

[b]Computed from data presented by Foster (1974) by proportion of area of zone IV to the total area of the site.

[c]Data from the U.S. Bureau of Mines (USBM, 1977, Table 5).

[d]Computed from data of Keesey (1976), considering that only reserves under the inner zones are precluded from development.

more than two-thirds of the potash resources would become available. Perhaps the most significant reduction would be in the impact on langbeinite: nearly three-fourths of the reserves can be reached by mining in control zone IV.

9.1.5 Plans for the Mitigation of Impacts

Like any construction project, repository construction will produce environmental disturbances: noise, erosion, pollution, disruption of wildlife habitats, and landscape alterations. This section reviews the plans for controlling these disturbances.

Landscape restoration

At the completion of construction, all areas disturbed by construction and not required for permanent facilities will be regraded and seeded.

Erosion

Erosion during grading and excavation will be controlled by diverting surface runoff from the construction and spoils areas either by sloping the grade away from these areas or by constructing a series of dikes and drainage ditches.

Mined-rock storage

While the mined-rock-storage area is being prepared, disturbed surfaces will be sprayed with water to control dust. Covered conveyors will move the mined rock from the mine-shaft headframe to a stacker conveyor, on which the mined rock will be sprayed lightly with water during its trip to the storage pile. Ditches will channel natural drainage water around the pile and retain runoff.

Terrestrial environment

Site access will be limited to designated roads, and traffic will be confined to these roads and to specific parking areas as much as practicable. Construction materials will be confined to specified laydown areas. These measures will prevent indiscriminate disruption of the desert habitat by the construction work force. Wastes produced during construction will be hauled to appropriate disposal areas for burial. After construction, all temporary buildings will be removed.

Pollution

Construction-related air pollution will generally be limited to the immediate area of the site. The largest source of pollutants will be the handling and transfer of soil, producing fugitive dust. To reduce this dust, permanent roadways will be paved and maintained. Frequently traveled areas will be overlaid with gravel or caliche and watered during working hours.

If a concrete batch plant is located at the site, dust from its operation will be controlled using best engineering practices. Combustion emissions from construction equipment will be controlled by the use of all applicable EPA emission controls. If burning of waste materials at the site is necessary, it will be carried out in compliance with all applicable regulations.

Litter will be controlled by the use of trash and scrap containers located throughout the site. The trash and scrap will be removed to an approved disposal area.

Fuels, lubricants, oily wastes, and other chemical wastes

All lubricants and other chemicals used during construction will be stored in approved standard containers with precautions against accidental spills or leakage. All fuels will be stored in conformance with applicable National Fire Protection Association and local codes.

Waste chemicals and oil will be collected in approved and clearly marked standard containers. The containers will be stored separately from other waste and removed from the site for reprocessing or disposal in an acceptable manner.

During site preparation and the early phases of construction, chemical toilets will be provided for sanitary wastes, which will be collected regularly and removed from the site for proper treatment and disposal. Once the sewage-treatment plant is completed, trailers with restrooms and day tanks for storage will be used until the entire system is completed. The day tanks will be emptied at the sewage-treatment plant.

Noise

The highest noise levels will occur in the daytime during site preparation and excavation. The impacts of noise will be reduced by limiting noisy construction work to daylight hours, by using equipment that meets the EPA noise-emission guidelines, and by maintaining and servicing equipment to insure that excessive noise is minimized.

The general public will not be affected by construction noise because the site is 18 miles from the nearest municipality (Loving) and 3 miles from the nearest resident.

9.2 EFFECTS OF PLANT OPERATION

This section describes the environmental effects of plant operation and discusses their significance. It also outlines plans for mitigating these effects.

9.2.1 Changes in Land Use

The construction and operation of the WIPP reference repository will remove some land presently being used for grazing (Section 9.1.1.1). During the life of the repository, a total of 620 acres will be preempted for surface facilities, rights-of-way, and biological and meteorological monitoring plots. Because the average grazing density on this land is about 6 to 9 head of stock per section, the carrying capacity of the area will be reduced by about 6 to 9 head of cattle.

The 140 acres occupied by control zone I and some parts of control zone II will no longer be available for recreation and hunting. No access restrictions or hunting controls are planned for areas away from these facilities.

9.2.2 Resources Committed

The natural resources committed for repository operation include energy derived from fossil fuels, water, chemicals, and laboratory equipment.

The energy consumed during operation will be primarily electrical energy. The normal operating electricity demand has been estimated to be 20,000 kilowatts. This power will be supplied by the Southwest Public Service Company (SPSC), which currently has a generating capacity of 2.7 million kilowatts. Industrial customers of SPSC that have recently ceased operation in the

Carlsbad area have used more power than the repository will require. The power for the repository will therefore not require additions to electrical power plants.

Diesel fuel will power waste-handling equipment both on the surface and in the mine and will supply the on-site generators during electricity-supply emergencies and when these generators are tested. The quantities of diesel fuel and gasoline that may be consumed during operation have been estimated to be 400 and 140 gallons per day (gpd) for the underground waste-handling equipment and the emergency generators, respectively. No natural gas will be used at the repository.

Water to be consumed by the repository will total approximately 25,000 gpd: 20,000 gpd for domestic needs and 5000 gpd for industrial needs. Where economically feasible, wastewater will be recycled to reduce consumption; for example, treated sanitary effluents will be used for landscape irrigation and dust control at the site.

The following chemicals will be used in sewage treatment, water treatment, and on-site experiments: sodium hypochlorite (NaClO) and gases such as hydrogen, helium, and hydrogen chloride. Laboratory equipment will consist of laboratory software (glass, tubing, etc.) and holding containers, some of which may be made of special metals such as platinum.

9.2.3 Effects of Mined Rock

During the operation of the repository, salt and other minerals will be removed from underground to provide new storage space. The 30-acre storage pile for the mined rock will hold materials to be used for backfilling the underground waste-disposal areas. Mined rock not needed for backfilling may be hauled from the site. Section 9.1.3 discusses the ways that the disposal of this mined rock will affect the environment during construction. The effects during operation will be similar.

No additional acreage beyond that already set aside in the construction phase will be needed for mined-rock storage. Because material will continue to be added to the pile during operation, fresh salt will be exposed to rain as well as to water sprayed from time to time for dual control. The incrustation process described in Section 9.1.3.1 will reduce the amounts of dust that are blown from the pile. The airborne material will not contaminate groundwater, although it will deposit on the soil. As explained in Section 9.1.3.1, field investigations of a 17-year-old mined-rock pile 9 miles from the reference site have supported the expectation that the mined-rock pile will exert no severe impacts on the environment.

9.2.4 Denial of Mineral Resources

Emplacement of radioactive waste in the repository will preclude for safety reasons the extraction of mineral resources from the geologic strata above or below the storage levels. The quantities and values of these resources are discussed in Section 9.1.4.

9.2.5 Effects of Noise

9.2.5.1 Normal Operating Noise

Normal operating noise will come primarily from control zone 1 and the mined-rock pile. It will be louder in the day than at night.

Noise standards

Noise-assessment criteria have been established by the U.S. Department of Housing and Urban Development (HUD, 1971). These criteria are presented in Table 9-13.

Table 9-13. Department of Housing and Urban Development Criteria for Noise Assessment (1971)

HUD assessment	8-Hour noise level (dBA)
Unacceptable	>75
Normally unacceptable	65-75
Normally acceptable	45-65
Acceptable	<45

On-site noise sources

There will be several noise sources within the site. Table 9-14 lists the primary sources and typical sound-pressure levels for them.

An overall sound-pressure level of 50 dBA can be expected 400 feet from the waste-handling building. This is within the range of the HUD acceptable-noise guidelines. At the James Ranch, the nearest off-site residence, about 3 miles away, the operating noise is expected to be inaudible.

Table 9-14. Typical Sound-Pressure Levels (SPL) for Operating-Phase Facilities

Noise source	SPL at 3 feet (dBA)
Water pumphouse	55
Hoist house	55
Transformer and switchyard	72
Mine construction exhaust	65
Train movement during unloading	75 (at 50 feet)

Mined-rock storage

The storage of mined rock will continue throughout construction and operation. Little fluctuation is expected in the noise level generated by this activity over the lifetime of the repository. The equipment used for the

storage area during construction (Table 9-3) is assumed to be the same as that needed during operation.

At 50 feet from the equipment, a maximum sound-pressure level of 97 dBA can be expected with all the equipment operating concurrently at full throttle and load. Rarely will all the equipment be operating simultaneously, and the sound-pressure level will be more typically in the upper 70s. At the James Ranch, this will be inaudible.

Overall operating noise

The overall operating noise is expected to be approximately 52 dBA at a distance of 400 feet from the waste-handling building. At the James Ranch, the noise will be inaudible.

Noise at the site will disturb some wildlife species (e.g., mule deer), but most of the resident species will become accustomed to the operational noise.

9.2.5.2 Standby Diesel Generators

Each of the three standby diesel generators is to be tested once a month for 1 to 2 hours. During the testing period, the noise from the diesel generator will be the predominant noise from the repository. Noise will radiate from the exhaust stack and through the air-intake louvers on the diesel-generator building. At the boundary of control zone I, the noise level is predicted to be 55 dBA. At the James Ranch, the noise will be inaudible.

9.2.5.3 Traffic

For purposes of noise estimation, it was assumed that approximately 400 people will be employed by the repository during the normal one-shift operation. The peak traffic load along the roads could be increased by a maximum of 400 cars per hour during commuting hours. The increase in passenger-car traffic will generate an L_{eq} of 52 dBA at 100 feet from the roads.

Truck traffic along the roads to the site will increase during operation. Some of the waste to be stored will arrive by truck, and there will also be trucks bringing supplies and materials. The number of passenger vehicles and trucks along U.S. 180 will be smaller during operation than during construction (Section 9.1.1). Noise levels are not expected to have a significant adverse impact on people or wildlife.

9.2.5.4 Railroad Noise

Most of the radioactive waste for the repository is to arrive by rail. To reach the repository spur, the rail cars may pass through Carlsbad and along the Santa Fe line to Loving. At normal operating speeds along this route, the train noise will be about 92 dBA at 100 feet from the tracks.

There are no residences within a mile of the proposed rail spur. The noise level during train passage along the spur should be about 55 dBA at 1 mile. This noise level should not cause any adverse impact. Wildlife will become quickly accustomed to these increased noise levels. At the closest residence, the noise level will be below 55 dBA.

9.2.5.5 Summary

At the James Ranch, the operating noise will be in the acceptable range (less than 45 dBA). Near the proposed new rail spur and along U.S. 180, the operating noise should be in the normally acceptable range (45 to 65 dBA).

9.2.6 Effects on Wildlife and Recreation

A fence will keep animals out of control zone I. There will be no migratory barriers at the site because antelope fences, which allow passage of deer and antelope, are planned for access roads, and other rights-of-way will not be fenced. Traffic on the access roads and railroad may be hazardous to nonmigratory animals; however, it will affect only populations within a few hundred feet on either side of the road.

Operational noise will frighten resident wildlife species, but after a period of time some animals will become acclimated to this kind of noise and return to their original habitat. Other, more sensitive, species will have been displaced from the area as a result of construction activities (Section 9.1.1.5). This disturbance should be a minor and insignificant impact.

The presence of new roads in the area will allow easier access for hunting and other outdoor activities. This improved access will lead to increased road traffic, and intermittent off-road excursions may disturb vegetation and wildlife. The people who move into the Carlsbad area to work at the repository may increase hunting pressure on wildlife in the area.

As the area becomes more accessible because of the new roads, amateur and professional archaeologists alike may be attracted to unexcavated sites there. It is possible that local pot-hunter clubs or individuals may view the development of the repository as an opportunity to hunt for local southwest-Indian artifacts.

9.2.7 Effects of Heat from Stored Waste

This section discusses the short-term temperature increases and mechanical effects produced in salt by heat from emplaced spent fuel. The long-term effects are discussed in Section 9.5.2.1. Since the spent-fuel demonstration will produce the greatest thermal loads in the underground waste-disposal areas, its effects bound those to be expected in other areas.

When subjected to high stresses and high temperatures, materials like salt deform. Continuing deformation under thermal and mechanical loading is called

creep. This phenomenon is important in the disposal of spent fuel, which will raise the temperature of the salt enough to accelerate the creep that will begin as an effect of the stresses brought on by mining. Creep may continue until it restricts operations near the spent fuel (e.g., by the closure of cavities).

To assess creep effects, the temperature rises associated with spent-fuel emplacement in the repository have been calculated by Thorne (1978). The calculation modeled the area for the disposal of spent fuel as a series of parallel tunnels mined at a 20% extraction ratio; spent-fuel assemblies were assumed to be stored in holes in the tunnel floors. The surrounding rock was treated as homogeneous salt with temperature-dependent thermal conductivity. The heat source was initially at a loading density of 30 kW/acre, and there was no cooling of open tunnels by ventilation. Calculations were made for times of up to 25 years after waste emplacement.

Figure 9-2 shows as a function of time the calculated temperatures in the floor, wall, and roof of a tunnel. The figure shows that the peak temperature rise in the tunnel occurs about 25 years after emplacement; the greatest increase, about 17°C, occurs in the floor of the tunnel.

The heat emitted by spent fuel in the RH-waste level of the repository will eventually reach the CH-waste level 600 feet above. To determine the temperature rise at the CH-waste level, calculations were performed with the computer code STEALTH, described in Section 9.5.2. These calculations showed that the temperature at the CH-waste level will rise by no more than about

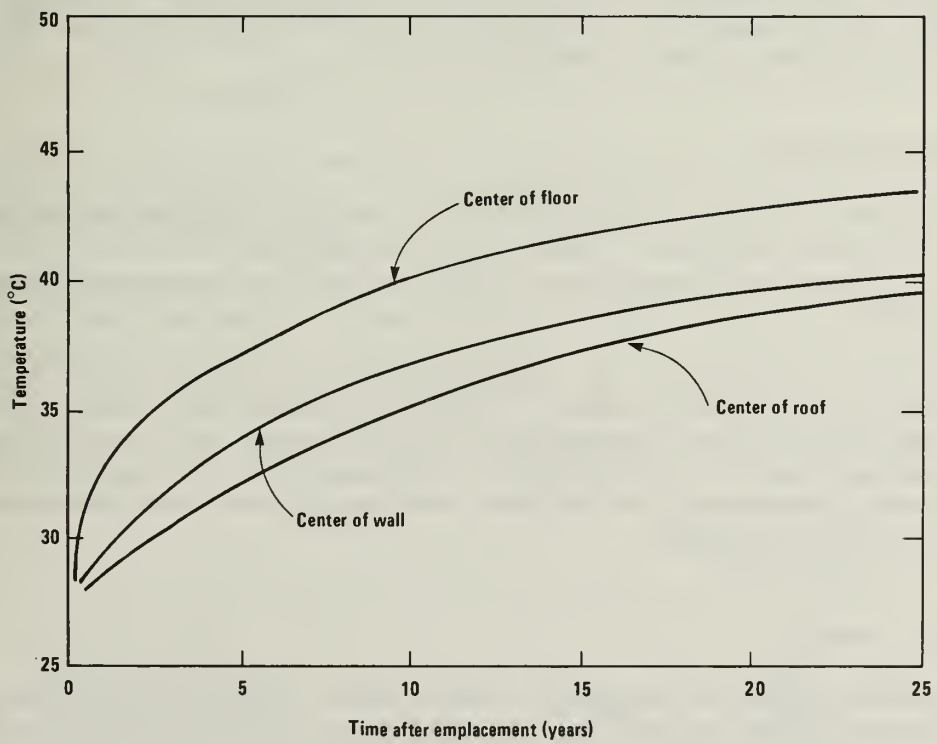

Figure 9-2. Time dependence of temperature in mined tunnel containing spent fuel.

2°C and that the peak rise will occur in the first few centuries after emplacement (Maxwell, Wahi, and Dial, 1978).

Because the creep of tunnel walls and pillars at the RH-waste level will eventually close the mine cavities, the rate at which the walls close in was calculated in a model WIPP geometry similar to that used in the temperature-rise calculations (Thorne, 1978). To assess an upper bound on this rate, a conservative creep law was used; the heat loading was assumed to be 30 kW/acre. The analysis predicted that the cavities will decrease to 27% of their original height within 25 years after spent-fuel emplacement. The actual creep closure of cavities in the RH-waste level will not be this rapid, but it will be an important consideration in detailed plans for retrieval.

9.2.8 Effects of Subsidence

The forces leading to subsidence will be continuously active from the beginning of mining, through operation, and into the long term. Since the effects are assumed to be greatest in the long term, they are discussed in the analysis of long-term impacts, in Section 9.5.2.2.

9.2.9 Effects of Nonradioactive-Waste Discharges

The sources of sanitary and other nonradioactive wastes generated during operation are described in Section 8.7. Although these wastes will be collected, treated, and disposed of, there is a possibility that they might adversely affect the environment. The potential adverse effects are described in this section for each type of waste.

9.2.9.1 Sanitary Waste

Sanitary-waste discharges during normal operation will amount to about 25,000 gpd of treated effluent. Most of the treated effluent will be used for landscape irrigation and dust control; the rest will be evaporated from the evaporation pond.

The effluent discharged by the sanitary-waste-treatment system will meet State water-quality standards (NMWQCC, 1977) for discharges onto or below the surface of the ground. The treatment of sanitary waste will not affect the quality of surface water or groundwater. The water in the evaporation pond will be of such quality that it will not contaminate the local groundwater if the lining of the pond breaks.

9.2.9.2 Solid Wastes

Solid wastes consist of sweepings, waste paper, and discarded equipment but do not include mined material, discussed in Section 9.2.3. During construction and operation, these wastes will be collected, compacted, and disposed of in a landfill in accordance with New Mexico Solid Waste Management Regulations adopted on April 19, 1974. The estimated size of the landfill area is about 5 acres.

Standard procedures at disposal sites involve continual disposal and backfilling on new as well as on used areas. This may result in natural revegetation at the landfill site as disposal cells are completed. As revegetation occurs, the disposal site will again become usable by local wildlife.

9.2.9.3 Chemical Discharges

As described in Section 8.7.5, the rate of salt release from the construction-exhaust shaft will be about 1050 lb/yr. Salt particles will be deposited on the ground in the surrounding area and may adversely affect vegetation, as described in Section 9.1.3.3.

Small quantities of waste hydraulic fluid, lubricants, etc., will be generated during operation. These materials will be disposed of in the sanitary landfill or sent away for salvage. In view of the small quantities involved, the environmental effects of these waste materials will be negligible.

A small quantity of nonradioactive wastes will be released as a result of experiments conducted at the repository. These experiments (described in Section 8.10) will produce small amounts of hydrogen from the corrosion of containers and the hydrolysis of brine, helium from radioactive decay, and hydrogen chloride (HCl) from brine decomposition (Section 8.7.5). The quantities are very small and therefore will have a negligible effect on the environment.

There will be three major sources of emissions from burnt diesel fuel: the emergency-power system, the surface handling equipment, and the underground handling equipment (Section 8.7.5). In addition, an oil-burning salt drier will be used at the mined-rock pile starting about 6 years after the repository begins operating. The total emissions from these systems are tabulated in Section 8.7.5 and summarized in Table 9-15.

The annual quantities of emissions from burnt fuel are very small in comparison with values obtained in a recent emission inventory for Eddy County, New Mexico (Table 9-16).

The unavoidable adverse impacts associated with the dispersion of salt and the release of nonradioactive gases will be a small fraction of those currently produced by activities in the region.

Table 9-15. Nonradioactive Emissions from Burnt Fuel[a]

Constituent	Annual total (tons/yr)
Hydrocarbons	3.2
Carbon monoxide	9.7
Nitrogen oxides	50
Sulfur dioxide	30
Particulates	3.2

[a]During one 8-hour work shift per day.

Table 9-16. Eddy County Emission Inventory[a]

Constituent	Inventory (tons/yr) Area source	Point source	Total
Hydrocarbons	4,373	4,351	8,724
Carbon monoxide	18,952	5,381	24,333
Nitrogen oxides	2,640	3,390	6,030
Sulfur oxides	231	22,301	22,532
Particulates	326	20,113	20,439

[a]Data obtained from the New Mexico Environmental Improvement Agency, February 1978.

9.2.10 Impact of Routine Releases of Radioactivity

The WIPP reference repository is designed to receive and store radioactive waste shipped from various sources across the country. The operation of the repository will require handling of packages and canisters, some of which may be externally contaminated. No canister will be opened, but very small quantities of nuclides may be released as a result of routine handling. The releases will be held to levels as low as reasonably achievable.

9.2.10.1 Exposure Pathways in the Environment

Radionuclides released to the environment can reach man through a variety of pathways, as shown in Figure 9-3. The pathways shown in the figure are the ones that were investigated in the analysis for this section. After the nuclides are released in the effluent gases, they may simply remain suspended in the air, or they may be deposited on the ground or on vegetation. The radiation dose received by these pathways can be external or internal.

Two of the pathways--air immersion and direct exposure from nuclides deposited on the soil--are external. An air-immersion dose results from nuclides suspended in air. The nuclides deposited on the ground are sources of direct exposure while a person stands on contaminated ground. Air immersion and direct exposure to nuclides deposited on the soil are external pathways since no material is actually taken into the body.

The other pathways result in internal exposure: the nuclides are actually taken into the body. Nuclides deposited on the ground may be taken up by plant roots and eventually ingested by a person who consumes the plant. The process can be even more complex. The food chain may involve an intermediary like beef or dairy cattle. The nuclides may be directly deposited on leafy vegetables or plants that are then consumed. Another possible internal pathway is inhalation. As can be seen, the pathways may be complex or quite simple. Although this list of exposure pathways is not exhaustive, it includes the potentially important pathways used in the analysis reported in this section. Usually, one of these pathways, the critical pathway, dominates the others.

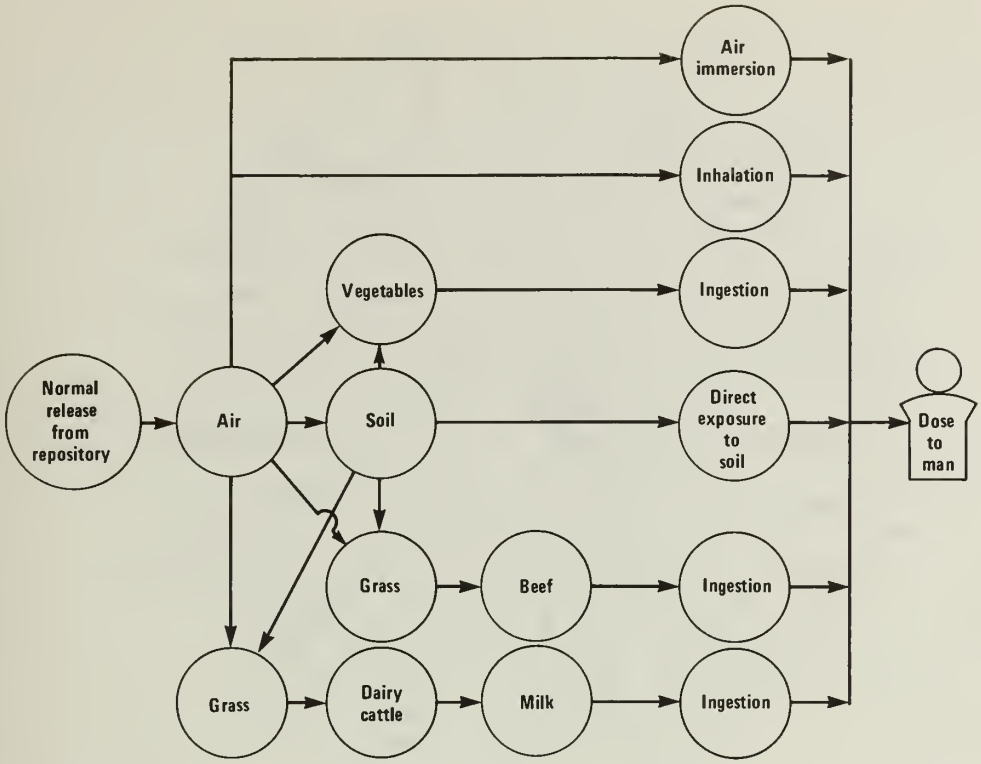

Figure 9-3. Primary pathways for nuclides released from the repository.

Each nuclide behaves differently in the environment. For example, some nuclides that have been deposited on the soil transfer from the soil through plant roots and concentrate in leafy plants, while others will not transfer from the soil. Still others will concentrate in the organs of domestic animals or wildlife that eat the plants and dirt clinging to roots. Usually one or two nuclides are the most likely to reach man and dominate the critical pathway.

9.2.10.2 Estimates of Exposure

Human exposure by the pathways described above was calculated by using a modified version of the computer code AIRDOS-II, as described in Appendix G. The input used for these calculations and the results are discussed below.

Nuclide releases and meteorological data presented in Section 8.6 and Appendix H, respectively, were used to calculate human exposure. The expected annual releases from the repository are given in Table 8-6. The annual average atmospheric dispersion factors for various distances of up to 50 miles and for each of the wind directions are given in Appendix H.

The study area was defined as the area inside a 50-mile-radius circle centered on the site. The area was divided into 16 wedge-shaped sectors (Figure 9-4), and each wedge was subdivided radially into 14 subsectors. In each subsector the population, agricultural area, significant water area, and beef- and dairy-cattle populations were defined. The inputs used are shown in Figures 9-4, 9-5, and 9-6. An attempt was then made to define the living

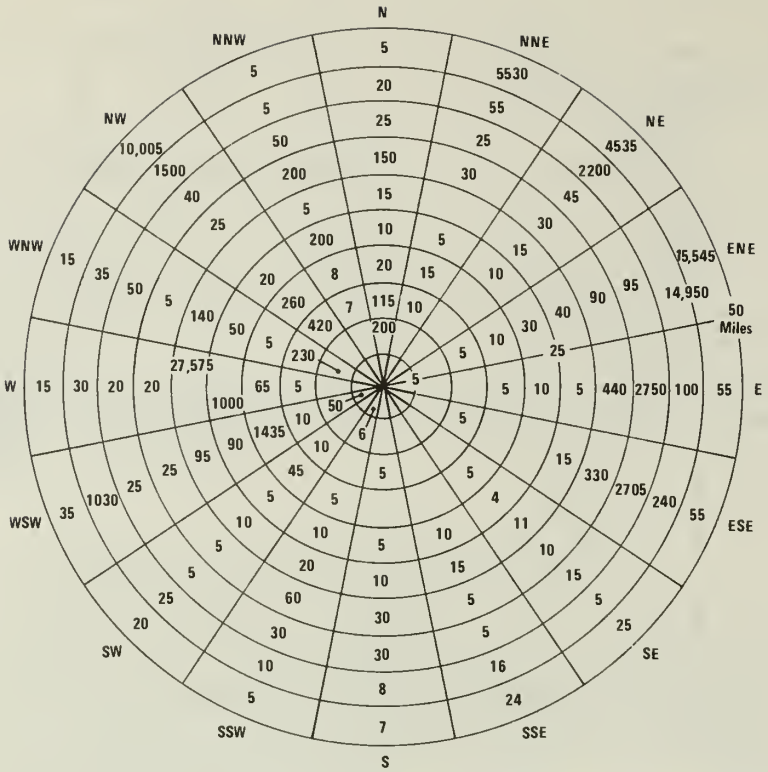

Figure 9-4. 1976 population within 50 miles of the site.

Figure 9-5. Agricultural areas. Values shown are millions of square meters cultivated in each sector. Shaded areas contain significant water, swimming might be possible in them.

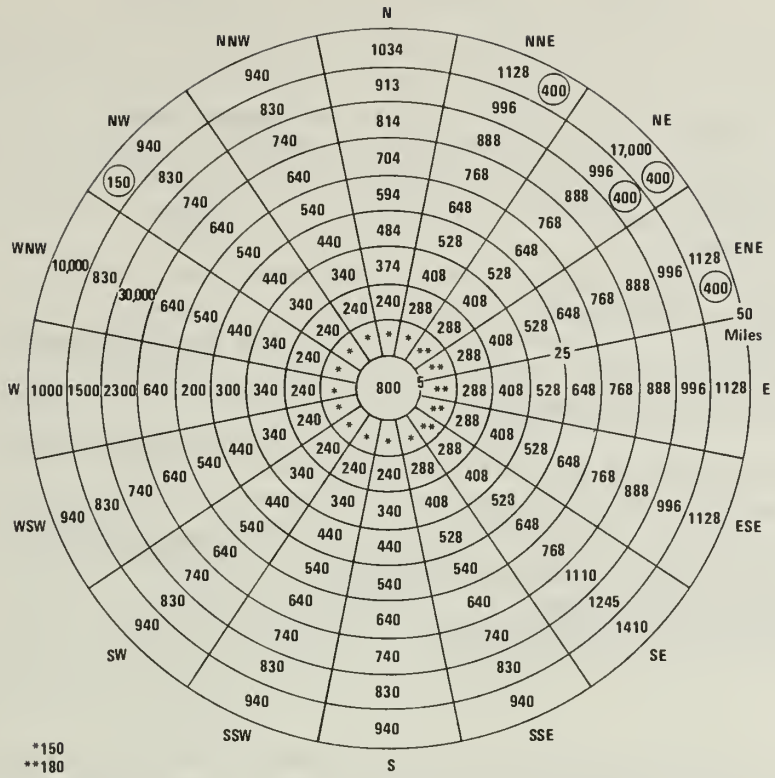

Figure 9-6. Beef cattle, sheep, and dairy cattle (circled) within 50 miles of the site.

patterns of people living in the subsectors. Living-pattern and some miscellaneous data used in the analysis are presented in Table 9-17. These and other data were obtained from conversations with county agricultural agents and from other sources listed in Appendix G.

As can be seen in Figure 9-5, there is little agriculture within the study area. Because fresh-produce-growing areas are quite limited in size, people in the study area were assumed to import 90% of their vegetables. Of the 10% not imported, a large fraction is assumed to be grown in home gardens. Few dairy herds exist in the study area (Figure 9-6), and the dairy farmers send their milk outside the study area to be processed and distributed. Therefore, it was estimated that only 1% of the milk consumed in the area is produced within it.

Beef-cattle ranching is the dominant agricultural pursuit in the study area. The sheep population was added to the beef-cattle population; this addition exaggerates the impact of beef. It was estimated that 50% of the beef consumed in the area is produced in the area, and an average individual was estimated to eat 0.3 kilogram of beef per day.

These data are shown in Table 9-17 as they were used to calculate radionuclide concentrations for the surrounding environs and to determine the radiological consequences to people.

Table 9-17. Living Patterns and Miscellaneous Data Used in the Analysis of Human Radiation Exposure

Input	Population	Individual
Fraction of vegetables imported	0.9	0.0
Fraction of beef imported	0.5	0.0
Fraction of milk imported	0.99	0.0
Fraction of vegetables produced in 50-mile radius that is produced in sector	Not applicable	0.1
Fraction of beef produced in 50-mile radius that is produced in sector	Not applicable	0.5
Fraction of milk produced in 50-mile radius that is produced in sector	Not applicable	0.01
Buildup time for surface deposition, years	15	15
Length of grazing season, days	365	365
Time from production to consumption		
Vegetables	14	14
Beef	20	20
Milk	4	4
Soil surface area furnishing food crops for one man, m^2	1000	1000
Pasture area per cow, m^2	121,000	121,000
Dry areal density of man's above-surface food, kg/m^2	0.25	0.25
Dry-weight areal grass density, kg/m^2	0.014	0.014
Depth of plow layer, cm	23	23
Rate of increase of steer muscle mass, kg/day	0.4	0.4
Mass of muscle at slaughter, kg	200	200
Soil density, g/cm^3	1.4	1.4
Fraction of beef herd slaughtered per day	0.03	0.03
Number of milkings per day	2	2
Beef consumption by man, kg/day	0.3	0.3
Milk consumption by man, kg/day	0.85	0.85
Vegetable consumption by man, kg/day	0.18	0.18
Milk capacity of udder, liters	5.5	5.5
Grass consumption of cow, kg/day	50	50
Milk production of cow, liters per day	11	11
Fraction of time spent swimming	0.01	0.01
Depth of water to be used for submersion doses, cm	152	152

Results

For convenience of calculation, the nuclides released were grouped by common characteristics. The groups are structural materials, fission products, actinides, and spent fuel. The groupings are self-explanatory with the exception of the spent-fuel group, which consists of three gaseous nuclides that are present in spent fuel only. Tritium, krypton-85, and iodine-129 are present in relatively large quantities in spent-fuel assemblies and are easily released if a spent-fuel canister is damaged.

Radiation doses and dose commitments were calculated for each of the nuclides in the four groups. If the exposure was external, a dose was calculated; if the exposure was internal, a dose commitment was calculated. When the exposure is external, the exposure lasts until the source is moved away. For example, if a person stands on a contaminated surface, he is exposed until he moves away from the surface. When a radioactive material is taken into the body, part of it remains in the body until it decays or is eliminated by biological processes. By convention, the annual dose given off by the radioactive material while in the body is integrated over a 50-year period after ingestion. The integrated dose resulting from each year's intake is called the 50-year dose commitment. For some materials that decay very quickly or are eliminated quickly, most of the dose commitment is received in the first year or two; for long-lived materials, the exposure lasts the entire 50 years.

Individual doses and dose commitments were calculated for a person living at the residence closest to the reference site (James Ranch, 3 miles to the south-southwest). Calculations were also made to determine an integrated population dose and dose commitment for all persons residing within the 50-mile study area. To calculate a population dose for a subsector, an individual dose is calculated and then multiplied by the population of the subsector in which the person resides. This calculation is performed for each subsector, and the sum of the individual subsector doses is the population dose for the study area.

The resultant doses and dose commitments for an individual are shown in Table 9-18 and for the population in Table 9-19. Since many pathways are involved, the tables are a summation of doses from external-exposure pathways and 50-year dose commitments from internal-exposure pathways.

Of the several nuclide groups, the greatest contributor to the overall impact is the actinide group. Within the actinide group, plutonium-239 contributes about 50% of the dose commitment. The rest of the impact is from the other plutonium isotopes, americium-241, and curium-244. The most important pathway for the actinides is inhalation.

The fission-product and spent-fuel groups are minor contributors to the impact. Within the fission-product group, the cesium isotopes are the principal contributors, and strontium is an additional significant contributor. The most important pathways for the fission products are ingestion and inhalation. Within the spent-fuel group, tritium contributes approximately 75% of the dose to the whole body, lungs, and bone. The remainder of the dose to these organs is from krypton. The pathways of importance for tritium exposure are inhalation and the ingestion of beef; the pathways for krypton are air immersion and

Table 9-18. Dose or Dose Commitment Received by an Individual Residing at the James Ranch

Group	Dose or dose commitment (rem)		
	Bone	Lungs	Whole body
Structural materials	7.7-10[a]	6.5-10	6.9-10
Fission products	9.7-8	1.2-8	2.8-8
Actinides	1.5-4	7.1-6	3.7-6
Spent fuel	3.4-8	3.5-8	3.4-8
TOTAL	1.5-4	7.1-6	3.8-6
Natural background	5.0	9.0	5.0
Five-hour jet flight			2.5-3

[a]7.7-10 = 7.7×10^{-10}.

Table 9-19. Dose or Dose Commitment Received by the Population Within 50 Miles of the Reference Repository[a]

Group	Dose or dose commitment (man-rem)		
	Bone	Lungs	Whole body
Structural materials	2.7-6[b]	2.0-6	2.2-6
Fission products	9.2-4	3.9-5	2.4-4
Actinides	4.8-1	2.2-2	1.2-2
Spent fuel	1.1-4	1.2-4	1.2-4
TOTAL	4.8-1	2.2-2	1.2-2
Natural background	4.8+5	8.6+5	4.8+5

[a]The population within 50 miles of the repository is 96,000.
[b]2.7-6 = 2.7×10^{-6}.

surface dose. The doses for the spent-fuel group are not, strictly speaking, annual doses; it is assumed in Section 8.6 that these isotopes will be released only once during the 4-year period of spent-fuel handling.

The overall impact from radionuclides released from the waste packages during normal operations is very small. The greatest individual dose commitment is 1.5×10^{-4} rem to the bone. This dose is to be compared with the 5-rem 50-year dose commitment from natural-background sources. This comparison is appropriate if the person receiving the dose lives at the James Ranch for 1 year. If he lives there for 5 years, his dose commitment would be approximately 5 times his first-year dose commitment; this value could also be compared with the 50-year dose commitment from natural background radiation. Thus the maximum dose commitment resulting from repository operation is to the bone and is 0.003% of that from natural background radiation.

The annual whole-body dose from repository operation is 3.8×10^{-6} rem to a person living at the James Ranch. This person would have to live at the

ranch for more than 650 years to receive a dose equivalent to that received from a 5-hour jet-plane flight.

An analysis was also made to determine the impact from the radon isotopes released during mining activities. This analysis, which does not include decay of the radon during transport from the site, considers an individual breathing the air at the James Ranch for a year. By assuming a continuous release during the year and by using calculated-annual-diffusion estimates for the site environs (Appendix H) the dose received by this person would be 2.5×10^{-7} rem/yr to the lung. This is 1.4×10^{-4}% of the natural background dose (0.18 rem for 1 year) to the lung.

Thus it is evident that the impact from the release of radon will be very small. Indeed, it will be no different from the releases at potash operations of similar size.

9.2.11 Radiation Exposure of the Work Force

The waste to be handled through the CH facility of the WIPP reference repository has a low surface-dose rate that permits the waste to be contact-handled. Nevertheless, this waste emits penetrating radiation, and some of the work force will be exposed to it. According to Section 5.1.2, a tentative acceptance criterion for CH waste is a maximum surface-dose rate of 200 mrem/hr on any one container and a maximum quarterly average of 10 mrem/hr. Experience with more than 60,000 drums of waste at the Idaho National Engineering Laboratory indicates that a 10-mrem/hr limit actually results in an average surface-dose rate of approximately 3 mrem/hr. Therefore calculations were carried out for an average of both 3 and 10 mrem/hr.

A prerequisite for calculating the radiation exposure of workers in the CH-TRU-waste facility is a reasonably detailed time-and-motion estimate. This involves estimating the various steps that have to be taken from unloading drums or boxes at the dock in the surface waste-handling building to the final stacking of these drums or boxes in the storage rooms underground, estimating the time each step will take, and estimating the distance of the operators from the waste for each step. Calculations were performed for a light 55-gallon drum containing paper, gloves, etc., for a heavy 55-gallon drum containing sludge, and for a Rocky Flats box containing contaminated metal. The heavy drum containing sludge resulted in the highest dose, and all results shown here pertain to that type of drum.

Exposures were estimated for a forklift operator and a transporter operator underground and for two different forklift operators on the surface. The resultant estimated exposures are shown in Table 9-20 for container surface-dose rates of 3 and 10 mrem/hr. These estimates are for average working conditions except that the aboveground exposures include the effects of a holding area full of drums waiting to be moved underground. The indirect or scattered dose is estimated to be 10 to 20% of the direct dose and is not included in the table.

These four workers would receive the greatest exposures from the operation of the CH-waste portion of the repository. The estimated exposures are well below the occupational dose limits of 5 rem/yr or 3 rem in any calendar quarter prescribed by regulation (10 CFR 20).

Table 9-20 Annual Exposure Estimates for Repository Workers

Worker	Average annual exposure (mrem)	
	Surface-dose rate = 3 mrem/hr	Surface-dose rate = 10 mrem/yr
Forklift operator (underground)	580	1900
Transporter operator (underground)	15	50
Forklift operator (aboveground--unloading)	250	830
Forklift operator (aboveground--pallet loading)	24	80

No estimates are yet available for radiation dose to workers in the RH-waste portion of the repository or for doses to workers that would result from accidents in any portion of the repository. Such estimates are being made to guide the choice of shielding and other design features so that all exposures of the work force will be below regulatory limits. The results will be reported in the Preliminary Safety Analysis Report due in 1979.

9.2.12 Effects of Decommissioning and Dismantling

This section discusses the environmental effects of decommissioning and dismantling: the expected radiological effects, the expected nonradiological effects, and the commitment of resources. The current decommissioning plan is described in Section 8.12.

All decommissioning activities will be performed under controls that will insure the safety of the general public and of the people involved in the decommissioning effort. This objective will be accomplished by the development of radiological-control and industrial-safety standards covering all activities. This development will be the responsibility of the DOE or its contractor responsible for the decommissioning. Where applicable, existing standards will be used; they will be reviewed for adequacy, and further investigations to develop adequate standards will be carried out when necessary. In addition, all detailed decommissioning plans will specify provisions for dealing with unusual or abnormal circumstances. At the time of decommissioning, the plans will be reviewed and approved by the DOE and any other Federal agencies under whose jurisdiction the decommissioning of the WIPP reference repository falls. Protecting both the public and the workers at the site, the procedures and standards will minimize the environmental effects of decommissioning.

Expected radiological effects of decommissioning

Because decommissioning involves disposal of contaminated equipment, it could expose the work force to radiation. Temporary shielding and extensive decontamination will insure that the exposures of workers are kept as low as reasonably achievable, in accordance with Federal guidelines at the time of decommissioning.

Although it is possible in theory that the public will be exposed to radiation, the exposure is expected to be insignificant. The special procedures taken to protect workers at the site will severely limit any radiation doses to the public. Packaging requirements will protect the public and the work force from radiation emitted by material shipped from the site.

Expected nonradiological effects of decommissioning

The decommissioning operation is expected to be similar to a heavy construction project in that the same type of heavy equipment will be used (e.g., dump trucks, bulldozers, grading equipment, and rail cars and engines). The environmental impacts will therefore be similar to those of construction, described in Section 9.4.1. The major impacts expected are an increase in noise and vehicular traffic, with associated dust and pollution. Control of the environmental impacts of decommissioning will use methods like those used during construction (Section 9.1.5).

The decommissioning is not expected to produce large quantities of chemical wastes; waste from decontamination operations will be handled in existing or temporary radwaste systems. Any additional facilities that may be required for these operations will be installed and operated in compliance with Federal, State, and local standards applicable at the time.

The decommissioning operation will not affect any known threatened or endangered species nor any historic or cultural sites.

The temporary socioeconomic impact of decommissioning will be an increase in employment, in that the process will require a decommissioning work force. The overall effect, however, will be a decrease in the size of the labor force once the repository is shut down.

Commitment of resources

Resources used during decommissioning will include water and construction materials for site preparation and mothballing. The primary use of water will be for decontamination. Some water will also be used in construction activities.

It is expected that most of the land will be returned to its original use--grazing; the area could, however, be made available for other uses since a railroad spur is at the site. As discussed in Section 8.12, these alternative uses will be investigated at a later time. To insure that the health and safety of the public are protected, appropriate security procedures will be established, and radiation monitoring and environmental surveillance will be carried out. Further discussion appears in Section 8.12.

9.2.13 Mitigation of Impacts

Mitigation of the environmental impacts will start with construction, as discussed in Section 9.1.5. Mitigating measures like noise abatement will continue through operation and decommissioning. Other measures that mitigate adverse environmental impacts throughout repository operation are summarized in this section.

Appearance

Surface structures are designed to minimize visual conflict with the natural features of the site. Simple forms, materials, textures, and colors will be used to blend with the desert environment.

Solid wastes

Standard procedures for the landfill consist of excavation, disposal, and backfilling over the waste. The solid waste will be layered with fill dirt for fly control and sprinkled with water to hold down dust. Low-lying areas will be selected to make the landfill unobtrusive, and natural drainage will be diverted around the site. Natural revegetation of the filled areas will be encouraged, and the site will eventually be suitable again for local wildlife.

Liquid wastes

Sanitary-waste effluents will undergo secondary treatment to meet State of New Mexico standards. Since these effluents will be contained in a lined evaporation-holding pond, they will not leak into the surrounding environment; aerobic decomposition will minimize odors.

Water from the suspect-waste and laundry building and decontamination areas will be processed in an evaporator.

Mined-rock pile

Measures for minimizing the impact of the mined-rock pile include several steps. The rock will receive a light water spray before being dumped on the pile. A ditch around the pile will keep salt-bearing water from running beyond the storage site.

Water consumption

Where economically feasible, wastewater will be recycled to reduce consumption; for example, treated sanitary effluents will be employed for landscape irrigation and dust control at the site.

Noise

By giving due consideration to noise-control engineering during the design phase, it will be possible for the repository to operate under normal conditions with a noise level barely perceptible at the nearest residence. Specific mitigation measures may include testing the standby diesel generators during daytime hours only, providing silencers for the diesel-generator exhaust, and locating most pumps inside structures.

9.3 ENVIRONMENTAL EFFECTS OF ACCIDENTS DURING OPERATION

Much of the planning for the WIPP reference repository has been an effort to insure that accidents occuring during the handling of radioactive waste of concern will pose no serious risk to the environment. This section reports the results of accident analyses performed as part of the planning. During repository operation two types of accidents might affect the environment: those that release radioactive material and those that release hazardous substances emitting no radiation.

The first part of this section discusses at length the accidents that might release radioactive material. It predicts the impacts that might occur during operations at the plant itself. The impacts were predicted by using the techniques of consequence analysis: postulating severe, yet credible, accidents and calculating their effects. To predict the effects realistically, the calculations use experimental data whenever applicable data are available.

The second part of this section discusses accidents that might release hazardous nonradioactive material. The third part discusses the effects of earthquakes, thunderstorms, and tornadoes.

9.3.1 Accidents Involving Radiation

To assess the environmental impacts of accidents that could release radioactive material, scenarios were developed to model severe accidents. Although all of these accidents are unlikely, the scenarios are realistic in the sense that they are not incredible; the accidents could, in theory, occur during repository operation. Each scenario was analyzed in detail to determine potential impacts to the general public. This approach yields a consequence analysis, not a risk analysis. Risk, which equals consequence times probability of occurrence, is difficult to define accurately because probability values used in determining risk are usually imprecise. This section presents the consequences of selected severe, but possible, accidents during plant operation and does not address the detailed probability of their occurrence.

During an accident, radioactivity can become available for release to the environment. The most serious release will result from an accident in which a shipping container or waste canister is damaged so severely that the waste is no longer contained.

Since the waste types vary in physical and radiological characteristics, available descriptive information was reviewed to determine the representative properties of each type of waste. These properties include physical forms, radionuclide inventory, and radioactivity; they are listed for each waste type in Appendix E.

It is difficult to state precisely how much of the material inside a container can become airborne, even though experiments have been conducted with certain waste forms under various accident conditions. Mishima and Schwendiman (1970, 1973a, 1973b) have measured the quantities of typical waste

materials that could become airborne. Even during fires, most of the activity does not become airborne; under most accident conditions, the fraction that becomes airborne is less than 1% of the volume of the waste. Similarly, in experiments not involving fire, most of the activity in various waste forms subjected to differing wind conditions does not become airborne.

The pathways of typical waste packages were followed step by step through the repository, from unloading in the receiving area to final storage in the mine. Accident scenarios were developed by reviewing the waste-handling procedures during each step. Normal operations with waste-handling equipment (transporters, forklifts, and hoists) were studied to determine how accidental misuse or equipment failure could result in the release of radioactive material.

Tables 9-21 and 9-22 list the postulated accident scenarios and identify each accident by number. The analysis of each scenario proceeded by establishing values for the factors that affect the amount of accidental release. For example, the analysis estimated the quantities of surface activity and of waste that could be released from inside a container, the number of containers involved in the accident, the fraction of the activity that could become airborne, and the decontamination factor of high-efficiency particulate air (HEPA) filtration. These factors were then combined to determine the total radioactivity released to the environment.

The scenarios were grouped into the following categories: (1) fires in the waste-handling building, (2) container failures in the waste-handling building, (3) underground container failures, and (4) underground fires. Within each of these categories, the scenario with the largest potential release of radioactivity to the environment was analyzed isotope by isotope as a representative and bounding example of that group. All other accidents within the groups would have less severe consequences.

The most severe accidents are the following:

1. A fire on the surface caused by internal combustion or an external combustion source.

2. Dropping and puncturing a waste package in the surface building.

3. Rupturing a container through failure of the mine hoist.

4. An underground fire ignited by an internal combustion source.

The least likely scenarios of the four mentioned are those involving fires. Fires from sources external to the waste containers would be infrequent and of limited size because of the lack of combustible materials in the handling areas. A fire started by internal combustion would be highly improbable because of the small amount of combustible waste. The lack of air inside the container would not allow a sustained combustion process, and expected waste-acceptance critera require most of the containers to be metal or combustion-resistant boxes. Indeed, engineering design of containers and fire-protection systems are expected to preclude radioactivity releases from fires.

Scenarios involving sources other than waste in containers were also investigated but were not found to be significant. One of these scenarios,

Table 9-21. Accident Scenarios for Contact-Handling Areas

Area	Accident	Possible scenario	Damage to waste package
Receiving	C1	Vehicle collision with waste package	No serious damage (package classified as Type B)
Unloading	C2	Drop of whole package from crane	One side of container damaged and crack in one drum (or box); crack is 2.75 $in.^2$
	C3	Drum drop on forklift (or down the dock)	Crack in one drum; crack is 2.75 $in.^2$
Pallet storage	C4	Drum puncture by forklift	Hole in side of one drum (or box); hole is 12 $in.^2$ (corresponding to size of forklift arm)
	C5	Drop from forklift	Crack in one drum; crack is 2.75 $in.^2$
	C6	Drum failure from excess internal pressure	Drum fails, releasing half the contents.
	C7	External fire	Contents of two drums (or one box) released because of internal pressure, and contents of one additional drum (or box) burned
	C8	Fire caused by internal combustion in drum (or box)	Surface contamination vaporizes from eight drums (or two boxes); contents of one drum (or one box) released because of internal pressure, and contents of one additional drum (or one box) burned
Overpack and repair	C9	Drum (or box) drops on way to repair	Crack in one drum; size of crack 5 times that of C3 since drum is defective initially
	C10	Drum (or box) fails on way to repair	Drum splits open, releasing 100% of contents
	C11	External fire	Surface contamination vaporizes from 24 drums (or two boxes); contents of two drums (or two boxes) released because of internal pressure, and contents of one additional drum (or box) burned
	C12	Fire caused by internal combustion in drum (or box)	Surface contamination from eight drums vaporizes (or two boxes); contents of one drum (or one box) released because of internal pressure, and contents of one additional drum (or one box) burned

Table 9-21. Accident Scenarios for Contact-Handling Areas (continued)

Area	Accident	Possible scenario	Damage to waste package
Cage loading	C13	Hoist drops down mine shaft	24 drums (or two boxes) crack open, releasing 100% of contents
	C14	Fire in hoist caused by internal combustion in drum (or box)	Surface contamination vaporizes from eight drums (or two boxes); contents of one drum (or one box) released because of internal pressure, and contents of one additional drum (or one box) burned
Underground storage	C15	Transporter hits pallet (or box)	Lid of one drum knocked off and cracks appear in sides of three other drums; cracks = 2.75 $in.^2$
	C16	Forklift punctures drum (or box)	Hole in side of one drum (or box); hole is 12 $in.^2$
	C17	Drums drop from forklift	Crack in one drum; crack is 2.75 $in.^2$
	C18	Rocks fall from mine shaft walls	Holes in sides of 12 drums; holes are 12 $in.^2$.
	C19	External fire during handling	Surface contamination vaporizes from eight drums (or two boxes); contents of one drum (or one box) released because of internal pressure, and contents of one drum (or one box) burned
	C20	Fire caused by internal combustion in drum (or box)	Surface contamination vaporizes from eight drums (or two boxes); contents of one drum (or one box) released because of internal pressure, and contents of one drum (or one box) burned
	C21	Backfilling equipment punctures drums	Hole in side of one drum (or box); hole is 12 $in.^2$ (corresponding to size of forklift arm)
Storage room	C22	Fire caused by internal combustion in drum (or box)	Contents of two drums released because of internal pressure, and contents of one drum burned

Table 9-22. Accident Scenarios for Remote-Handling Areas

Area	Accident	Possible scenario	Damage to waste package
Receiving	R1	Cask drops	No serious damage to canister because cask is a Type B packaging
	R2	Crane impacts on cask	Same as R1
	R3	Fire around transport vehicle during inspection of cask	Same as R1
	R4	Cask drops	Same as R1
	R5	Cask overturns from transport roller	Same as R1
Decontamination and cooling	R6	Dry cask with defective canisters, break in flexible hose	Loss of radioactive gas
	R7	Wet cask with defective canisters, break in coolant pipe	Loss of radioactive fluids
	R8	Cask drops	No serious damage to canister because cask is a Type B packaging
Hot cell	R9	Hot-cell crane knocks over canister	Crack in canister
	R10	Canister drops	Crack in canister
	R11	Fire from internal combustion in canister	Contents of one canister burn; surface radioactive material vaporizes
	R12	External fire involving high-level waste for experiments	Same as R11
Canister decontamination	R13	Contaminated-waste-discharge line breaks during canister decontamination	Loss of radioactive fluid to decontamination cell
	R14	Fire from internal combustion in canister	Contents of one canister burn

Table 9-22. Accident Scenarios for Remote-Handling Areas (continued)

Area	Accident	Possible scenario	Damage to waste package
Hoist-cage-loading station	R15	Hoist drops down waste shaft	One canister and facility cask broken
Underground transfer cell	R16	Canister drops	Crack in canister
	R17	Fire from internal combustion in canister	Surface radioactive material vaporizes from one canister, and contents of one canister burn
	R18	External fire involving high-level waste for experiments	Surface radioactive material vaporizes from one canister
Storage room	R19	Canister drops in hard salt	Crack in canister
	R20	Fire in transport vehicle	No serious damage to canister because it is protected by a shielding cask
	R21	Fire from internal combustion in canister	Contents of one canister burn

for example, was failure of tanks in the liquid-radwaste system with the subsequent evaporation of some of the radioactive liquids. The radiological consequences of such an accident would be small because the radioactive inventories in each tank are limited.

In general, accidents that could occur during the retrieval of waste from the repository are expected to be no more severe than those that could occur during emplacement since waste will be retrieved by a reversal of the emplacement process. Contact-handled TRU-waste containers will be removed one at a time so that each container can be inspected. If a container is found to be breached or externally contaminated, it will be overpacked at the retrieval site (Section 8.11). Remotely handled TRU waste will also be retrieved by removing the buried canisters one at a time. Again, if the canister is externally contaminated, it will be overpacked or removed by overcoring and then placed into a new container. Because of the proposed inspection and overpacking procedures and unit-by-unit retrieval, accidents during retrieval would be limited to a single container. Accidents involving multiple packages could not occur until a batch of containers became available for transport. Accidents involving the transport of retrieved waste would be similar to, and bounded by, transport accidents during emplacement.

Description of accidents in the CH-waste area

The two most common waste containers in the area where CH TRU waste will be handled will be the DOT-17C drum (55-gallon steel drum) and the DOT-7A plywood box (4 by 4 by 7 feet) with a 3-millimeter-thick fiberglass-reinforced, fire-retardant polyester coating.

Because the number of boxes expected at the repository at any time is much smaller than the number of drums, the number of accidents involving boxes is expected to be much smaller than the number involving drums. For this reason, only the accident scenarios involving drums were analyzed even though, on the average, drums contain about 35% less radioactivity than do boxes.

Listed below are the general assumptions used for analyzing the accident scenarios for the CH-waste area:

1. Surface activity on the waste containers is many orders of magnitude lower than the activity inside. Since the waste containers are breached during the scenarios, the surface contamination is not explicitly included because its contribution is insignificant.

2. Contact-handled TRU waste is expected to have various forms; much of the waste is expected to be metal scrap, rags, sludge, and sludge-concrete mixes. Data from Shefelbine (1978) support a conservative assumption that 10% of the waste is in powder form and that 25% of the waste is combustible.

3. The air-entrainment factor for waste (respirable-size particles only) exposed in the accidents is 0.014% per hour. This value, which expresses the rate at which waste of respirable size will become airborne, comes from experiments by Mishima and Schwendiman (1973a), who deposited uranium dioxide powder on a roadlike surface and subjected it to a 2.5-mph breeze. They found that in 6 hours 0.14% of the powder became airborne and 62% of the airborne material was respirable.

Because the maximum wind speed through the storage area is 0.5 mph, the 0.014% factor is conservative.

4. Studies of the release of radioactivity during fires have been performed by Mishima and Schwendiman (1970, 1973b). When simulated TRU waste contained in a cardboard box was burned, a wide range of values was obtained. For engineering and laboratory-scale experiments, the percentages of activity released and respirable were 0.23% and 9.8%, respectively. These values represent maximum values resulting from ideal conditions for combustion. For the scenarios described here, an intermediate value, 1%, was used.

5. A 10^6 decontamination factor is allowed for the two-stage HEPA filters. This is believed to be a reasonable allowance; it is based on an experimentally determined (ACGIH, 1977) removal efficiency for test particles with diameters larger than 0.3 micron.

Brief descriptions of all the accident scenarios and the resulting damages are summarized in Table 9-21. Four accidents--C7, C10, C13, and C22--were chosen for a detailed calculation of isotope-by-isotope release to the environment. These accidents represent the limiting or worst accident for their respective categories: surface fire, surface container failure, underground container failure, and underground fire. Table 9-23 lists the activity release by isotope for these accidents. Synopses of each of the four accident scenarios are given below.

C7: Surface fire. The lack of flammable materials in the building makes the following assumption reasonable: if a fire occurs in the surface facility, not more than the contents of one drum will burn and not more than two adjacent drums will pressurize and burst because of the heat. As a plausible way for a fire to start, it is postulated that a small puddle of diesel oil spilled under a pallet of waste drums somehow ignites; while such a fire would be small, the adjacent drums are assumed to fail and spill half their contents. The contents spilled from the adjacent drums do not burn, and only 10% of the spilled material is in powder form.

It takes 1 hour to put out the fire and to repack or cover the exposed waste. Since only 25% of the drum content is combustible and 1% of the activity in the combustible contents is released in respirable form per hour, the burning releases a total of 0.25% of one drum in respirable form. In addition, since 0.014% of the spilled powdered waste from the adjacent drums is released and respirable per hour, a total of 0.0014% of one drum is respirable and released from the material that is not burned. The quantities are then further reduced by HEPA filtration before they are released to the environment.

C10: Surface container failure. In this scenario, a forklift runs into a defective drum, which is assumed to split open, releasing all its contents. The waste is exposed to the air for 1 hour before it is repackaged or covered to prevent further waste from becoming airborne. Only 10% of the waste is in powder form, and 0.014% of the exposed waste that is powder becomes airborne and is respirable. Thus, a total of 0.0014% of the waste in one drum is airborne and respirable and reaches the HEPA filters.

Table 9-23. Radioactivity of Respirable Material Released to the Environment During Representative Accidents in the CH TRU-Waste Handling Area

Isotope	Radioactivity (Ci) released in accident scenario			
	C7[a]	C10[b]	C13[c]	C22[d]
Pu-238	1.0-10[e]	5.7-13	1.4-10	2.0-10
Pu-239	1.2-9	6.7-12	1.6-9	2.4-9
Pu-240	2.9-10	1.6-12	3.9-10	5.8-10
Pu-241	7.2-9	4.0-11	9.8-9	1.4-8
Am-241	2.0-11	1.1-13	2.7-11	4.0-11
TOTAL	8.8-9	4.9-11	1.2-8	1.7-8

[a]Surface fire.
[b]Container failure.
[c]Underground container failure.
[d]Underground fire.
[e]1.0-10 = 1.0×10^{-10}.

C13: Underground container failure (hoist drop). If the hoist cage drops down the shaft because of mechanical or electrical failure, all 24 drums on a pallet are assumed to rupture, releasing their contents. Only 10% of the waste is in powder form. The air-entrainment factor of 0.014% per hour is increased in this scenario by a factor of 10 because of the turbulence created by the fall; the experiment on which the original factor is based studied a gently deposited powder. The waste is exposed to the air stream for 1 hour; after this time workers will have covered the waste to prevent further release. The equivalent of 0.34% of the waste in one drum is airborne and respirable and reaches the HEPA filters.

C22: Underground fire. An underground fire, like the surface fire, should affect no more than three drums; this scenario assumes that one drum burns and two burst in the heat of the fire. Since access to waste in the mine is limited, the duration of the accident is assumed to be 2 hours (instead of the 1 hour assumed for a surface fire). All other assumptions for the underground fire will be the same as those for the surface fire (C7). Because of its longer duration, this accident will, however, release twice the activity released in scenario C7.

Description of accidents in the RH-waste area

Operations in the RH-waste area will handle RH TRU waste, experimental vitrified high-level waste, and canistered commercial spent-fuel assemblies. The physical and radiochemical properties of these waste packages are described in Appendix E. The accidents that can occur in an RH area are the same as those in a CH area.

The analysis of accidents in handling RH waste makes six assumptions:

1. Before a canister enters the hot cell, no damage serious enough to release radioactivity can occur to the canister because it is overpacked with a Type B shipping cask.

2. The air-entrainment factor used for CH TRU waste is used for RH TRU waste as well.

3. When a canister containing glass impacts at a velocity of 117 ft/sec, less than 0.1% of the contents is broken into particles that are 10 microns or smaller (Smith and Ross, 1975). This result is used for the hoist-drop accident with a high-level-waste (glass) canister. Even though the impact velocity of a hoist drop can be more than 300 ft/sec, it is judged that 0.1% is still conservative because the hoist cage and the transfer cask will provide two layers of impact absorption and shielding.

4. If spent-fuel assemblies are involved in a hoist-drop accident, the same 0.1% as in assumption 3 above is used for nongaseous radionuclides because both the spent-fuel cladding and the transfer cask would have to be breached before broken fuel pellets could be exposed to air in the mine. The R15 accident discussion presents the assumptions for gases.

5. For accidents involving fire, 25% of the RH TRU waste is assumed to be combustible. Since RH TRU waste is not well characterized, 25% is a conservative upper limit derived from the composition of CH TRU waste. The RH TRU waste will probably contain much less combustible material than CH TRU waste. Neither high-level waste (glass) nor spent fuel will burn. One percent per hour of the total activity in the burning RH TRU waste is released in a respirable form (the same as the amount released for CH TRU waste).

6. A decontamination factor of 10^6 is allowed for the two-stage HEPA filters. Removal credit is not taken for tritium, krypton-85, and iodine-129, because they are gases.

These factors and assumptions are used to make conservative, yet realistic, judgments regarding possible accidents.

From the list of Table 9-22, three scenarios resulting in the greatest release of radioactivity were chosen for detailed isotope-by-isotope calculations: surface fire (R11), hoist drop (R15), and underground fire (R21). Table 9-24 lists the isotopes released in these accidents. The accidents are described below.

R11: Surface fire. The only waste in the RH-waste area that is combustible is RH TRU waste. Since the RH facility handles one canister of RH TRU waste at a time, only one canister is involved in a fire. Only 25% of the RH TRU waste is combustible; of the amount that is combustible, 1% becomes airborne and respirable. Thus the equivalent of 0.0025 canister reaches the HEPA filters. The fire is put out and the waste is assumed to be repacked or covered in an hour.

R15: Underground container failure (hoist drop). If the hoist cage drops down the shaft, a canister and its transfer cask will be damaged. It is conservatively assumed that all the contents of the canister will spill out. Only one canister will be involved in this accident since the hoist is designed to carry only one canister in a transfer cask at a time. The damaged

Table 9-24. Activity of Respirable Material Released to the Environment During Representative Accidents in the RH-Waste-Handling Area[a]

Accident R11: Surface Fire		Accident R21: Underground Fire	
Isotope	Activity (Ci)	Isotope	Activity (Ci)
Sr-90/Y-90	1.1-6[b]	Sr-90/Y-90	2.2-6
Co-60	6.6-9	Co-60	1.3-8
Ru-106/Rh-106	9.2-9	Ru-106/Rh-106	1.8-8
Cs-137/Ba-137m	5.3-9	Cs-137/Ba-137m	1.0-8
Eu-152	1.3-9	Eu-152	2.6-9
Eu-154	5.3-9	Eu-154	1.0-8
Th-232	3.0-12	Th-232	6.0-12
U-234	2.4-14	U-234	4.8-14
U-235	1.0-12	U-235	2.0-12
U-238	2.2-11	U-238	4.4-11
Pu-238	2.7-10	Pu-238	5.4-10
Pu-239	3.2-9	Pu-239	6.4-9
Pu-240	7.6-10	Pu-240	1.5-9
Pu-241	1.9-8	Pu-241	3.8-8
Am-241	5.3-11	Am-241	1.1-10
Cm-244	1.3-8	Cm-244	2.6-8
TOTAL	1.2-6	TOTAL	2.4-6

Accident R15: Underground Container Failure (Hoist Drop)

RH TRU waste		High-level waste		Spent fuel	
Isotope	Activity (Ci)	Isotope	Activity (Ci)	Isotope	Activity (Ci)
Sr-90/Y-90	5.9-8	Sr-90/Y-90	6.9-7	H-3	45
Co-60	3.7-10	Ru-106/Rh-106	4.5-9	Kr-85	780
Ru-106/Rh-106	5.2-10	Sb-125	6.9-9	Sr-90/Y-90	2.5-7
Cs-137/Ba-137m	3.0-10	Te-125m	2.9-9	Ru-106/Rh-106	1.9-9
Eu-152	7.4-11	Cs-134	8.1-8	I-129	4.5-3
Eu-154	3.0-10	Cs-137/Ba-137m	9.6-7	Cs-134	3.6-8
Th-232	1.7-13	Ce-144/Pr-144	1.1-9	Cs-137/Ba-137m	3.4-7
U-234	1.4-15	Pm-147	7.8-8	Pm-147	3.0-8
U-235	5.8-14	Sm-151	1.3-8	Eu-154	2.0-8
U-238	1.2-12	Eu-154	5.1-8	Np-237	1.3-12
Pu-238	1.5-11	Eu-155	1.6-9	Pu-238	1.1-8
Pu-239	1.8-10	Np-239	2.1-10	Pu-239	1.2-9
Pu-240	4.3-11	Pu-238	1.1-9	Pu-240	1.9-9
Pu-241	1.1-9	Pu-239	1.8-11	Pu-241	2.6-7
Am-241	2.9-12	Pu-240	4.8-11	Pu-242	5.6-12
Cm-244	7.4-10	Pu-241	3.6-9	Am-241	5.6-9
		Am-241	1.9-9	Am-242m	3.4-11
		Am-242m	9.9-11	Am-243	7.8-11
		Am-243	2.1-10	Cm-243	1.3-11
		Cm-242	2.5-11	Cm-244	7.6-9
		Cm-243	3.3-11		
		Cm-244	1.9-8		
TOTALS	6.3-9		1.9-6		825

[a]These lists radionuclides are truncated from those in Appendix E. To perform the truncation the ratio of activity to permissible concentration in air was calculated for each radionuclide. These lists contain the radionuclides with the highest values for that ratio.

[b]1.1-6 = 1.1×10^{-6}.

canister may contain RH TRU waste, experimental high-level waste (glass), or commercial spent fuel. Each of these forms requires a different set of assumptions:

1. For RH TRU waste, the release rate of respirable material is assumed to be 0.14% per hour (0.014% per hour x 10) of the released powder; the factor of 10 allows for the impact of the drop as in scenario C13. The fraction of waste that is powder is assumed to be 10%. The waste is assumed to be exposed to air for 1 hour before it is repacked or covered.

2. If a canister of experimental high-level waste (glass) is in the dropped hoist cage, 0.1% of the contents is assumed to be broken into particles 10 microns or smaller. Three hours elapse before the waste is repacked or covered; hence, 0.42% (0.14% x 3) of the powder is entrained in the air in respirable form.

3. For spent fuel, 0.1% of the canister contents is assumed to be crushed into particles 10 microns or smaller by the impact of the hoist drop. The duration of this accident is assumed to be 6 hours because clean-up personnel might not be allowed at the accident scene until the gaseous tritium and krypton-85 had been thoroughly vented. Multiplying 0.84% (6 hours at 0.14% per hour) by the powdered inventory gives the airborne and respirable release for all isotopes except tritium, krypton-85 and iodine-129. For these three gaseous isotopes, the total gap activity (i.e., the activity between the fuel pins and the cladding) is assumed to be released during the first hour after the hoist drop. Gap activity is taken to be 30% of the total amount of these three isotopes in the spent-fuel assembly. The Reactor Safety Study gave 10% as the fraction of krypton-85 and iodine-129 released to the gap (NRC, 1975, Table VII 1.1). The more conservative 30% factor from NRC Regulatory Guide 1.25 is chosen here for the accident analysis. No credit for removal by HEPA filters is taken for tritium, krypton-85 and iodine-129.

R21: Underground fire. All assumptions for the underground fire accident are the same as those for the surface fire except that the duration is assumed to be 2 hours instead of 1 hour. The underground accident is expected to last longer because access to the accident would be restricted.

Dose estimation

Radiation doses are calculated from values for three parameters: the quantity of radioactivity released, χ/Q (atmospheric diffusion factor), and population distribution. These values were input to AIRDOS-II, a computer code (Moore, 1976) that traces each nuclide from the point of its release through the biosphere to man. AIRDOS-II and the modifications made to use it with directly input χ/Q values are discussed in Appendix G.

The nuclide releases given in Tables 9-23 and 9-24 were converted to release rates for each scenario. The χ/Q values required by AIRDOS-II were taken from the 1-hour-period 50th-percentile tables in Appendix H. A deposition velocity of 1 cm/sec was assumed for all respirable particles. The population distribution was the same as that in Section 9.2.10.

Pathways and doses received by people

For accident scenarios, the pathways by which nuclides can reach people are restricted to three: direct inhalation of nuclides, immersion in air, and exposure from nuclides deposited on the ground. Inhalation and immersion in air are the dominant pathways for the gaseous isotopes released from the spent fuel, while the most important pathway for most other radionuclides is inhalation. The ingestion pathway is not included since administrative controls would be imposed on the disposition and sale of contaminated foodstuffs during an emergency situation.

The two important pathways expose people in different ways. Air immersion is an external-exposure pathway in which no radioactive material remains in the body. Once the radioactive material has passed (i.e., after the plume has dispersed), no additional exposure is received; the exposure is expressed in terms of a dose. Direct inhalation is an internal pathway in which material is taken into the body and remains until it is biologically removed. Since the residence time may be many years, the exposure received is expressed in terms of a dose commitment. By convention, the contribution of the residing radionuclides is integrated for 50 years after their intake; the integrated dose is called the 50-year dose commitment.

In this analysis, doses and dose commitments were calculated for a person living at the James Ranch, the residence nearest to the site, and for the population within 50 miles of the study area. As stated earlier, the 50th-percentile χ/Q values were used in the calculations. The χ/Q value at the James Ranch was used to determine the individual doses. For the population-dose calculations, the wind was assumed to blow continuously during the accident period into the sector where the highest population dose would occur. The highest dose sector was determined by calculating the population dose for each sector and then selecting the sector with the highest population dose. Only the dose to the general public is calculated; doses to workers at the repository will be treated in the forthcoming preliminary safety analysis report.

Results

The dose commitments resulting from the accident scenarios for CH TRU waste are presented in Table 9-25 for individuals and Table 9-26 for the population. Since most of the exposure due to the CH TRU waste results from the direct inhalation of radionuclides, the values in the tables are dose commitments. The greatest percentage of the dose commitments results from plutonium.

The CH-TRU-waste scenario involving an underground fire (C22) would have the greatest impact; nevertheless, the impact on the general public would be negligible. Consider the bone-dose commitment for a person living at the James Ranch. Should an accident like C22 occur, this person would receive 1.1×10^{-8} rem to the bone over a 50-year period. During 50 years, however, natural background radiation will contribute a dose of 5 rem to the bone. The dose from the accident would be a small fraction of the naturally occurring background exposure. None of the hypothesized scenarios for CH TRU waste could result in a significant dose to the public.

Table 9-25. Dose and Dose Commitment Received by a Person Living at the James Ranch

Accident scenario	Dose or dose commitment (rem) Bone	Lung	Whole body	Skin	Thyroid
CH Area					
Surface fire (C7)	5.5-9[a]	2.7-10	1.3-10		
Surface container failure (C10)	3.2-11	1.6-12	7.5-13		
Hoist drop (C-13)	7.8-9	3.9-10	1.8-10		
Underground fire (C22)	1.1-8	5.5-10	2.6-10		
RH Area					
Surface fire (R11)	3.6-8	2.9-9	1.7-9		
Hoist drop (R15)					
RH TRU waste	1.9-9	1.5-10	8.7-11		
Experimental HLW	2.5-8	2.4-9	1.5-9		
Spent fuel	8.7-6	1.0-5	8.3-6	2.2-4	3.2-5
Underground fire (R21)	7.2-8	5.7-9	3.3-9		
Natural background[b]	5.0	9.0	5.0	1.0-1	4.0
5-hour jet flight[c]			2.5-3		

[a] 5.5-9 = 5.5×10^{-9}

[b] Data from the National Council on Radiation Protection and Measurements (NCRP, 1975).

[c] Mid-latitudes at 38,000 feet.

Table 9-26. Dose and Dose Commitment Received by the Population in the Worst Sector[a]

Accident scenario	Dose or dose commitment (man-rem) Bone	Lung	Whole body	Skin	Thyroid
CH Area					
Surface fire (C7)	1.3-5[b]	6.5-7	3.1-7		
Surface container failure (C10)	7.2-8	3.7-9	1.8-9		
Hoist drop (C13)	1.8-5	9.2-7	4.3-7		
Underground fire (C22)	2.5-5	1.3-6	6.1-7		
RH Area					
Surface fire (R11)	8.0-5	6.5-6	3.8-6		
Hoist drop (R15)					
RH TRU waste	4.2-6	3.4-7	2.0-7		
Experimental HLW	5.8-5	5.4-6	3.4-6		
Spent fuel	2.0-2	2.3-2	1.9-2	5.1-1	7.4-2
Underground fire (R21)	1.6-4	1.3-5	7.5-6		
Natural background	1.4+5	2.6+5	1.4+5	2.9+3	1.1+5

[a] 28,700 people live in the "worst sector."

[b] 1.3-5 = 1.3×10^{-5}.

The results of accidents involving RH TRU waste are also presented in Tables 9-25 and 9-26. The pathway of importance for RH TRU waste and experimental high-level waste is the direct inhalation of radionuclides; the pathways of most importance for spent fuel are air immersion and inhalation. Since these important pathways include both internal and external exposures, Tables 9-25 and 9-26 report values for both doses and dose commitments. For RH TRU waste and experimental high-level waste, the most significant nuclides are cobalt-60, strontium-90, cesium-137, plutonium isotopes, americium-241, and curium-244; for spent fuel the most significant nuclides are krypton-85, tritium, and iodine-129.

The scenario involving spent fuel (R15) has the greatest impact. The dose to the lung of an individual at the James Ranch would be 0.00001 rem. This value is, however, many orders of magnitude smaller than the corre- sponding 50-year dose from natural background radiation, which is 9 rem. Furthermore, it would take 300 years of exposure at the James Ranch to equal the whole-body dose received by a person during a 5-hour jet-plane trip.

Two additional organs, skin and thyroid, are included for the spent-fuel radionuclides. The air-immersion pathway for krypton-85 would result in an increased external dose to the skin. The annual skin dose for the individual at the James Ranch would be 0.00022 rem. This number may be compared to an annual natural-background-radiation dose to the skin of approximately 100 mrem. The thyroid dose comes from iodine-129. The person living at the James Ranch would receive a 0.000032-rem dose commitment to the thyroid. The 50-year thyroid-dose commitment from natural background radiation is 4 rem.

Judged by comparison to doses received from natural background radiation, the doses to the general public that would result from any of the accident scenarios are very small.

In addition, waste-acceptance criteria, engineering design of waste canisters, and engineering design of fire-protection systems in the mine-storage rooms are expected to prevent fires or at least limit their extent so that the scenarios involving fire can be disregarded. The maximum impact is not changed by eliminating the scenarios involving fire; however, half of the credible scenarios are eliminated.

The impacts discussed above assume that the HEPA filters function properly. If for some unforeseen reason, however, the HEPA filters were not working, most of the impacts would be increased by a factor of 10^6 because credit could no longer be taken for the 10^6 filter factor. The exception is the spent-fuel accident; the gases from spent fuel are not filtered at any time, and hence their impact would not increase. The doses and dose commitments incurred are presented in Table 9-27.

Without the HEPA filters, the underground-fire scenario would provide the greatest impact. The dose commitment to the person living at the James Ranch would be 0.072 rem to the bone. This value is still well below background levels; the dose commitment of 0.072 rem is only 1.5% of the 50-year dose from natural background radiation. If engineering design precludes fires, the most serious accident will then be the spent-fuel hoist drop. The impact of this scenario is about the same as that of the fire.

Table 9-27. Dose and Dose Commitment Received by a Person Living at the James Ranch if HEPA Filters Are Not Functioning

Accident scenario	Dose or dose commitment (rem)				
	Bone	Lung	Whole body	Skin	Thyroid
CH Area					
Surface fire (C7)	5.5-3 [a]	2.7-4	1.3-4		
Surface container failure (C10)	3.2-5	2.0-6	1.0-6		
Hoist drop (C13)	7.8-3	3.9-4	1.8-4		
Underground fire (C22)	1.1-2	5.5-4	2.6-4		
RH Area					
Surface fire (R11)	3.6-2	2.9-3	1.7-3		
Hoist drop (R15)					
RH TRU	1.9-3	1.5-4	8.7-5		
Experimental HLW	2.5-2	2.4-3	1.5-3		
Spent fuel	7.0-2	3.7-3	2.2-3	2.2-4	7.2-4
Underground fire (R21)	7.2-2	5.7-3	3.3-3		
Natural background[b]	5.0	9.0	5.0	0.1	4.0
5-hour jet flight at 38,000 feet			2.5-3		

[a] $5.5\text{-}3 = 5.5 \times 10^{-3}$.

[b] Data from the National Council on Radiation Protection and Measurements (NCRP, 1975).

9.3.2 Nonradiological Accidents Affecting the Environment

Accidents that might affect the environment without dispersing radionuclides are releases of chemicals, fuels, or other toxic materials as a result of chemical explosions, fire, or structural damage. While some such accidents could be caused by natural events, this section discusses accidents that might occur during the handling of materials inside the repository. The potential for these accidents will be reduced by facility design, including surface structures hardened to prevent the release of radioactivity, fire-protection systems, the isolation of hazardous materials, and protective dikes and berms. Preparing contingency plans and being ready with cleanup procedures will further reduce the possibility of affecting the environment.

Explosive, flammable, or toxic materials that may be released as a result of an accident include sodium hypochlorite, used in wastewater- and potable-water treatment; hydrogen gas, hydrogen chloride, and chemicals used in on-site experiments; and diesel fuel for standby power generators and waste transporters. It is not known at present how much of these materials will be stored at the site. Since only a health-physics laboratory will be located at the site, it is anticipated that the laboratory chemical supplies kept at the site will not be large enough to pose a hazard. Furthermore, all potentially

hazardous materials to be kept at the site will be stored in such a way as to minimize environmental hazards, as shown by the following examples:

1. Sodium hypochlorite will be stored in an open area in reinforced containers. State fire and safety codes for the use of this chemical in water treatment will be followed. The rupture of a container will not itself result in an environmental effect. However, on exposure to heat (e.g., sunlight) the sodium hypochlorite will release chlorine gas. Since the storage area will be open, any chlorine gas released would be diluted and dispersed.

2. Hydrogen gas and other explosive or combustible laboratory materials will be stored in clearly marked modular containers in a well-ventilated area to prevent buildup to explosive concentrations.

3. Diesel fuel will be stored in a tank surrounded by a dike that will contain any leakage from the tank.

4. Corrosive chemicals such as hydrochloric acid will be stored in clearly labeled corrosion-resistant containers.

These precautions will preclude hydrogen gas explosions and prevent the spread of flammable or toxic material in quantities or concentrations sufficient to endanger the health and safety of the public.

9.3.3 Effects of Natural Forces

9.3.3.1 Earthquakes

All surface buildings and systems that are essential for the safe handling of radioactive waste are designed to withstand any earthquake accelerations that might be expected to occur at the site during the life of the facility. Therefore earthquake-induced releases of radioactivity to the environment are not likely (the effects of other accidental releases of radioactivity are discussed in Section 9.3.1).

Strong earthquakes may damage other surface structures (the evaporation pond and sewage-treatment plant, the mined-material disposal systems, the administration building, and other support structures), but failure of these structures and systems would not affect the buildings and systems designed to withstand earthquakes. The failure of the structures and systems might result in the release of sewage, fuels, or chemicals, but this would not cause an off-site effect since the soil would absorb any spillage. There is a possibility of fire in such an event, but firefighting equipment and procedures would be available to quickly control any fires.

Very little is known of the effects of earthquakes underground; they are, however, expected to be less severe than those on the surface. The most adverse impact would be a cave-in, which would be handled in the same manner as any other mine cave-in with respect to personnel survival. If retrieval of buried wastes were required, it would be carried out as described in Section 8.11.

9.3.3.2 Thunderstorms

Thunderstorms, with their high winds, heavy precipitation, hail, and lightning, can cause destruction; the damage, however, is usually less than that caused by tornadoes.

High winds and their possible effects are discussed in Section 9.3.3.3. All structures essential to the safe operation of the repository are designed to withstand winds with speeds of up to 183 mph. However, high winds may disperse mined material over a larger area than normal.

Hail is not a significant environmental problem. All structures necessary for radiologically safe operation are designed to withstand the impact of a tornado-driven missile, and the impact of a hailstorm would be trivial in comparison.

Large amounts of precipitation within a short period of time may be of concern. The average annual rainfall for southeastern New Mexico is only 13 inches. However, a maximum 24-hour rainfall of 5 to 6 inches can be expected about once in 100 years. At the site, rainfall soaks into the sandy ground very quickly, and only occasionally dose a severe storm produce enough rain to cause water to flow over the ground surface. Because the nearest perennial stream, the Pecos River, is 14 miles from the site, floods caused by heavy precipitation will not occur. A minor concern is the washoff and wind dispersion of the mined material on the conveyor. The mined-rock pile will be protected from runoff by a ditch.

9.3.3.3 Tornadoes

All surface buildings and systems essential for the safe handling of radioactive waste are designed to resist tornado-force winds, tornado-driven missiles, and sudden pressure changes. A tornado would damage other buildings and scatter some of their contents; it would also scatter material in the open, such as salt from the mined-rock pile and liquids from the sewage pond, but this damage would not affect the tornado-resistant buildings.

Access to the underground storage areas can be gained through the four shafts that link the underground storage areas to the surface and therefore to surface events such as tornadoes. A tornado produces a sudden drop of surface atmospheric pressure, which might disrupt the ventilation system and cause some damage to ventilation equipment. The exhaust fans will not be affected by a tornado because they are in tornado-resistant structures. Since all air leaving the underground storage areas would continue to be filtered, no radioactive materials would enter the atmosphere.

9.4 ECONOMIC AND SOCIAL EFFECTS OF PLANT CONSTRUCTION AND OPERATION

9.4.1 Project Description and Setting

The socioeconomic impacts discussed here are based on the conceptual design for the construction and operation of the WIPP reference repository. The impacts and their distribution have been computed by economic modeling techniques that used an input-output procedure with a substantial effort in on-site inspection.

Two communities have been closely analyzed for substantial impact: Carlsbad in Eddy County and Hobbs in Lea County--the only two sizable communities close to the reference site. Two scenarios have been developed for the analysis: scenario I assumes maximum impact on Carlsbad, while scenario II deals with a higher impact on Hobbs than is assumed in scenario I. Both scenarios deal with the highest levels of expected impact.

This analysis assumes that the construction of the repository will begin in mid-1981 and end late in 1984. During that time, the number of construction workers in the surrounding labor-market area will increase. An underground-construction phase, similar to a mine development or mine-construction operation, will take place concurrently with the surface-construction phase.

In addition to the workers employed by the construction contractor or subcontractors, certain employees of the Federal Government, Sandia Laboratories, and the Westinghouse Electric Corporation are expected to be maintained in the local area. While the number of these employees will vary over time, it will increase as the construction phase proceeds. To simplify this analysis, these individuals and their impact on the economy will, unless stated otherwise, be included in references to construction activity.

As a result of the construction and mining activities, industries serving the population and those servicing other businesses (mainly some manufacturing, service, and wholesale operations) will experience increases in business volume and the need for additional employees.

The socioeconomic analysis assumes that the impact will be spread over both Eddy and Lea Counties. A survey* of labor-location patterns for the potash industry in the area of the site shows that approximately 88% of the work force lives in Carlsbad, 11% in the remaining portions of Eddy County, and approximately 1% in Lea County. For scenario I, the direct impact of construction and operation is assumed to follow this established pattern, while the indirect impact is spread as follows: 80% to Carlsbad, 10% to areas outside Carlsbad in Eddy County, and the remaining 10% to Lea County.

A survey of the large mining companies in the area revealed that one company had a significantly different employee-location pattern. This company

*This analysis is based on personal interviews with county clerks in Lea County (February 1978), Eddy County (February 1978), Loving County (February 1978), Winkler County (March 19, 1978); U.S. Geological Survey, various maps; Bureau of Land Management land-use maps; New Mexico Highway Department, Planning Division, Quadrangles of the State of New Mexico, 1963 and 1965.

had recruited through offices in Hobbs. The employee-location distribution for this company served as a model for scenario II, which indicates that Lea County, particularly the city of Hobbs, will receive a greater impact from WIPP construction and operation. The distribution of direct and indirect impacts for scenario II is as follows: Eddy County, 58%, with Carlsbad receiving 54%; and Lea County 42%, with Hobbs receiving 36%.

Procedures used to project employment, population, housing, income, and other socioeconomic effects are explained in Appendix L.

9.4.1.1 General Economic Impacts of the WIPP Reference Repository

During repository construction, approximately $224.6 million will be expended for labor, equipment, and other construction costs, including expenditures for associated nonconstruction activities.* The economy of Eddy and Lea Counties will receive $95.9 million in direct new expenditures (labor and local procurements). Throughout the construction phase an estimated additional $32.7 million will impact the economy of the two counties by associated nonconstruction activities. This figure covers labor costs and local procurements. Thus, the total direct impact from both construction and associated nonconstruction activities will be $128.6 million during the 3.5-year construction period. Indirect effects in the private sector will total an estimated $115 million. The greatest local economic impact (direct and indirect) during a single year is expected to be about $94 million during the third year of construction (1983).

As construction ends and the repository becomes operational, the economic impact will change significantly. Beginning in 1985 some $35.6 million will be spent annually for the operation phase; only $14.3 million will directly affect the area economy. The total local economic impact of the operation phase, both direct and indirect, will amount to almost $30.5 million annually.

9.4.1.2 Other Events with Economic Impact

In November 1977, Beker Industries and the Duval Corporation announced decreases in their Carlsbad-area labor forces of 100 and 200 employees, respectively. These two events loosened up the labor market in Carlsbad in terms of <u>future</u> activity within the area.

The Brantley Dam, an earthen dam to be built on the Pecos River between Artesia and Carlsbad, will begin construction just before 1980. It will probably take 3 to 4 years to complete and will employ fewer than half the workers expected on the WIPP project. Many of the workers will be heavy-equipment operators. Its construction period will overlap the beginning of WIPP construction, thus having some effect on the overall availability of labor in the Carlsbad area. This fact has been recognized in computing information for the WIPP reference repository.

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*Unless otherwise stated, all dollar figures are in constant 1978 dollars.

9.4.1.3 Employment

Much of the information presented in this subsection is summarized in Table 9-28, which shows, for each year of construction and operation, the number of jobs supported by the WIPP repository and the number of newcomers to the two-county area. These projections end in 1987 because it is assumed that the impact of repository operation will be static by then.

Jobs directly connected with the WIPP repository have been estimated from information supplied by Sandia Laboratories, the Bechtel Corporation, and the Westinghouse Electric Corporation. Jobs indirectly supported by construction and operation have been computed by a region-specific (Eddy and Lea Counties) input-output modeling process (see Appendix L).

Construction phase

Construction is expected to take 42 months, beginning in mid-1981. It is expected that by the end of 1981 approximately 588 new jobs will have been created by the construction phase and associated nonconstruction activities. Of this number, just more than 500 jobs will be directly related to construction, while just more than 80 jobs will be connected with the associated nonconstruction activities within the area. Average employment for the 6-month period has been established at approximately 284 construction-related jobs and 60 nonconstruction-related jobs.

During 1982 employment is expected to increase dramatically. It is expected that by the end of the year, just more than 1100 new positions will have been created by both the construction phase and the associated nonconstruction activities in the area. Average employment during 1982 will be approximately 700 jobs in construction and 149 jobs in associated nonconstruction positions.

In 1983 employment is expected to reach a peak. Direct construction-activity jobs are expected to peak in mid-1983 at just fewer than 1100. Associated nonconstruction positions should increase throughout the year, numbering approximately 325 by the end of 1983. Combined employment for construction and associated nonconstruction is expected to reach just more than 1380 by the end of 1983. The average number of construction jobs in 1983 should be just fewer than 1040, while the average for nonconstruction jobs should be approximately 270 for the year.

Because construction is expected to be completed by the end of 1984, the number of construction positions should decrease throughout the year. Average employment in construction for 1984 is estimated to be 550. Associated nonconstruction jobs, however, will increase throughout 1984, with the average number of jobs estimated to be 389. By the end of 1984 an operational level of 440 jobs is expected to be reached.

Based on survey information on construction workers (Old West Regional Commission, 1975) and an inspection of job-applicant data for Eddy and Lea Counties from the State Office of Employment Security, projections suggest that approximately 56% of the workers directly employed in construction will be persons not now residing in the area; the remaining 44% will be drawn from the labor force in Eddy and Lea Counties.

Table 9-28. Yearly Averages of the Numbers of Jobs Supported by the WIPP Reference Repository, Lea and Eddy Counties

Year	Direct jobs--construction period				Indirect Jobs	Total Jobs	Newcomers per year[a]
	Surface	Mining	Nonconstruction	Subtotal			
1981	216	68	60	344	418	762	600
1982	540	164	149	853	1,204	2,057	1,200
1983	805	233	269	1,307	1,834	3,141	1,250
1984	425	125	389	939	1,371	2,310	(400)
	Direct jobs--operation period						
	Surface	Mining	Storage	Subtotal			
1985	286	109	49	444	661	1,105	(1,150)
1986	286	109	49	444	661	1,105	(300)
1987	286	109	49	444	661	1,105	0

[a]Gain (or loss) of population in the two-county area resulting from the reference repository.

The number of indirect, or spinoff, jobs supported by the construction and associated nonconstruction activities of the repository will vary significantly during the 3.5-year construction period. The maximum impact on spinoff, or indirect, jobs is expected to occur in 1983. The number of these jobs to be filled by newcomers migrating to the area because of the WIPP repository is difficult to determine. However, the area is now experiencing a significant population growth that is expected to continue. Therefore, the assumption has been made that approximately half the jobs created indirectly by construction will be filled by newcomers attracted by the opportunities in construction.

During construction, the unemployment rate in the two-county area should drop substantially, to approximately 3.5%. This is not unusual for these counties: in 1976 Lea County experienced monthly unemployment rates as low as 3.1% and an overall average of 4.3% for the year. During the 1960s, when economic conditions in the two-county area were somewhat depressed, the unemployment rate was 3.8% in 1963 and as low as 2.8% in 1968 (ESCNM, 1970-78). However, a level of 3.5% characterizes an area with a labor shortage, given current unemployment rates and conditions throughout New Mexico and the United States.

Operation phase

As operation begins and construction is completed, population and employment characteristics will change significantly. The number of workers will decrease; repository operation will directly employ an estimated 444 persons. Most of these (286) will be directly connected with the general operation of the plant, while 109 persons will work on continuing mining operations, and approximately 49 in the ongoing storage operations. In addition, approximately 661 jobs will be supported indirectly.

Therefore, the total number of jobs both directly and indirectly created by the operation phase will be about 1,105. This level is expected to be achieved by the end of 1984.

The nature of the operational jobs will require a significant training period for the operational personnel, who will be hired throughout the construction period to be trained by the operating contractor. Thus, the expected level of operational employment (444) will be reached by the end of 1984. While radioactive waste will not be received until 1986, the 444 workers will be employed in "shake-down" operations, whose impact on the economy will be the same as that of actually storing radioactive waste during the first year of operation.

Several important aspects should be noted concerning the operational phase. In economic terms, the operational impact will be significantly smaller than the impact of construction. Moreover, the shuffling of population caused by losses of construction and mine-development jobs and gains in operation jobs will occur from 1984 through 1986. Thus, significant inmigration and outmigration will result, not only because the number of jobs will change but also because the required skills will change.

Studies of large construction projects have shown a lag in the outmigration of individuals once a project has been finished. It is therefore expected that the unemployment rate may increase by 0.5 to 1.0% for

1 to 2 years after construction is complete. Because of the expected lag, and the influx of individuals to the operational jobs, the population loss during 1984 will be relatively small. In the following years, however, it is expected that many will seek employment elsewhere, causing more than 1800 people to move out of the two-county area. Total population there may drop slightly or fail to grow during 1985.

9.4.1.4 Personal Income

Construction phase

During repository construction, more than $84.8 million in new personal income will flow into the two-county economy in direct wages and salaries from construction and associated nonconstruction activities. In addition, about $36.1 million in wages and salaries will come from businesses indirectly affected.

Personal income from interest, dividends, and rent will add another $19.5 million during the 3-year-plus period. About $141 million will be derived directly and indirectly in the private sector from repository construction through 1984. In the public sector, about $6.1 million in personal income will result from increased activity in the area and the additional State- and local-government employment required for support. Thus the total personal income added to the area during construction will be $146.5 million over 3 to 4 years. However, net loss from transfer payments (generally Social Security payments) will decrease this to $138.9 million.

Operation phase

The personal income to be derived from repository operation will be significantly less than that derived during construction. As explained in Section 9.4.1.1, the amount of new money flowing directly into the economy during a normal year of operation will be approximately $14.3 million. Although this amount may vary with expenditure patterns in repository operation, this study uses a constant figure of $14.3 million. This figure is significantly different from the local direct expenditures of more than $29.0 million during the peak year of construction. Because the direct impact is lessened, clearly the personal-income impact will be lessened.

The estimated $14.3 million annual flow directly associated with repository operation will affect new personal income as follows: (a) approximately $9.1 million will be realized from direct wages and salaries; (b) another $4.8 million will come from wages and salaries in businesses indirectly affected; (c) about $0.8 million per year will be derived from government expenditures; (d) about $2.3 million will come from dividends, interest, and rents. During the first years of operation, net transfer payments will be negative, and later they will have a net positive effect. Because of this balancing effect, transfer payments for an average year have been considered neutral. The net result, therefore, will be an increase in total personal income of approximately $17.0 million annually.

Personal-income distribution: scenario I

Carlsbad will receive approximately $117.6 million (net) of the additional personal income generated by repository construction; other areas inside Eddy County but outside Carlsbad will receive nearly $14.7 million. Additions to total personal income in Lea County will amount to about $6.6 million. These impacts will be spread over a 3- to 4-year period. During the operation phase, the annual personal income impact on Carlsbad is expected to be $14.3 million. Total countywide impact (including Carlsbad) will be $16.1 million. Lea County should receive $0.9 million annually.

Personal-income distribution: scenario II

In scenario II, in which more of the impact goes to Hobbs, $58.3 million in new personal income will flow into Lea County during construction, with $50.0 million of this entering the economy of Hobbs and the remainder going to areas in Lea County outside Hobbs. While the impact on Eddy County in scenario II is significantly lower than that in scenario I, the total income flow during construction is still substantial: $80.6 million. Of this amount, $75.0 million will directly enter the economy of the City of Carlsbad, with the remainder going to other parts of the county.

As operation begins, the impact will be substantially decreased, with new personal income totaling approximately $7.1 million annually in Lea County and $6.1 million in Hobbs. The annual impact in Eddy County is slightly higher, with $9.9 million for the county and $9.2 million for the City of Carlsbad.

9.4.2 Population

9.4.2.1 Population Growth

During the first year of repository construction (1981) approximately 600 persons will migrate to the area as a result of construction and other repository-induced activities (Table 9-29). In 1982, an additional 1200 people will be attracted, and in 1983 the construction phase will bring in an additional 1250 immigrants. Thus, the 3-year cumulative (1981-1983) total addition to the population of the two-county area will be 3050 people. As the construction effort phases down in 1984, a loss of about 400 persons is expected.

The beginning of operation in 1985 should result in a loss of 1150 immigrants directly or indirectly associated with the WIPP. It is projected that approximately 300 people will leave in 1986, producing a total population loss of 1850 due to the completion of construction; this net change in population should remain constant throughout operation at 1200.

Interviews with city officials (C. Tabor, City Manager, Carlsbad, 1978; K. Gleason, Assistant City Manager, Hobbs, 1978) indicate that both Carlsbad and Hobbs will be able to accept the growth associated with the repository. Both cities have departments or agencies that carry on planning and associated functions and approve new subdivision development.

Table 9-29. Population Migration Resulting from Jobs Directly and Indirectly Related to the WIPP Reference Repository[a]

Year	Direct jobs		Indirect jobs		Total jobs	
	Annual migration	Cumulative migration	Annual migration	Cumulative migration	Annual migration	Cumulative migration
1981	450	450	150	150	600	600
1982	650	1100	550	700	1200	1800
1983	600	1700	650	1350	1250	3050
1984	(450)	1250	50	1400	(400)	2650
1985	(600)	650	(550)	850	1150	1500
1986	0	650	(300)	550	(300)	1200
1987	0	650	0	550	0	1200
2010	0	650	0	550	0	1200

[a]Population rounded to the nearest 50 persons.

Distribution of population: scenario 1

As explained in Section 9.4.1, scenario I reflects the current patterns of place-of-residence choices of potash-company employees in the area; most of the WIPP-induced population change occurs in Eddy County. In 1981, 600 people will move into the two-county area because of construction. Most are expected to locate in Eddy County, with Carlsbad housing more than 500 new residents. Lea County is expected to receive fewer than 50 people in 1982 as a result of the project. The impacts in 1982 and 1983 are somewhat different. In 1982, another 1200 newcomers are expected in the two-county area. Most of these people (1125) will locate in Eddy County. Carlsbad should receive about 1000 new residents, while in Lea County new residents will number between 50 and 100. The pattern in 1983 will be similar, with 1250 new residents in the two-county area.

The construction and operation of the repository will exert maximum population impact on Eddy County in 1984, with a total of 3050 new residents; 2580 will locate in Carlsbad. The maximum impact in Lea County is projected at 150 new residents in 1983, with fewer than 100 during operation.

Overall population levels with WIPP-induced population changes under scenario I are indicated in Table M-1 of Appendix M.

Distribution of population: scenario II

While the number of people migrating to the two-county area is the same in scenario I and II, the distribution of population is significantly different. Of the 600 immigrants attracted by the WIPP in 1981, about 350 will locate in Eddy County and 250 in Lea County. Carlsbad and Hobbs will receive 320 and 220 new residents, respectively.

The second year of construction will bring in another 1200 people: 500 into Lea County and 700 into Eddy County. Hobbs will receive an expected additional 430 people; Carlsbad should receive approximately 650. In 1983 an additional 1250 people should be attracted by construction; these people will be distributed between counties in about the same pattern.

The peak population impact on Lea County and Hobbs will occur in 1983, with 1280 new county residents, 1100 of whom will locate in Hobbs. After the transition from construction to operation, the net population addition to Lea County is projected at 500 people, with Hobbs receiving 430. In Eddy County the net population increase due to the impact of the operation phase should reach 700, with some 650 locating in Carlsbad. Population projections for the area under scenario II conditions are indicated in Table M-2 of Appendix M.

9.4.2.2 Population Within 10 and 50 Miles

Population within 10 miles of the site is expected to change little in the foreseeable future. Only one new permanent residence is planned for construction, about 8 miles west-southwest of the site (Mobley, personal interviews, 1978).

Mining employment within 10 miles of the site may vary significantly with the national market for potash or with the level of existing mining operations. However, the outlook for New Mexico potash demand and the current level of operations do not appear to dictate any large changes in the commercially associated daytime population within the area. The population associated with the many oil and gas wells in the area varies from day to day and is difficult to predict.

Within the 50-mile radius, the population is expected to increase significantly at certain locations. The 50-mile radius includes parts of three counties in New Mexico and parts of six counties in Texas. The population change in Lea and Eddy Counties through the year 2000 will be concentrated in incorporated population centers previously identified.

Tables M-3 through M-9 in Appendix M show the anticipated population within 50 miles of the site in 1980 (1 year before construction begins), in 1990, in 2000, and in 2010. Many of the areas show extremely low population figures. Accurate forecasting for these areas is impossible since a variation of less than 100 people causes a high percentage variation in population figures. The population change for these sparsely populated areas is based on trends established in areas within the counties outside of incorporated places and a continuation of activity now existing within each of the defined radius sections. Between 1980 and 2000, the population within the 50-mile radius is expected to increase by just more than 47,000 persons, or about 47% during the 20-year period. The WIPP project, however, will account for less than 3% of the total growth during that time if, in fact, the population levels projected for those time periods are accurate.

9.4.3 Social Structure

As discussed in Section 9.4.1, the WIPP reference repository will account for only a small part of the growth in Eddy and Lea Counties. For this reason, it will have little effect on the social and cultural institutions of the two counties.

The most widely recognized negative results that the public expects from a large construction project are strains on public services, housing shortages, and increased crime resulting from an influx of "rough" construction workers. While repository construction will create a temporary housing shortage, it will place no appreciable strain on public services; nor will it attract large numbers of outsiders compared to the existing population. Those who do migrate to the area will probably be people of similar backgrounds, occupations, and transiency. In terms of their probable concerns, area residents can anticipate more jobs, more business opportunities, and a temporary housing shortage.

The WIPP may affect some classes and ethnic groups slightly more than others, but it will have relatively little effect on the region's community organizations or political activities.

9.4.3.1 Sociocultural Impacts

The composition of income and occupational groups in Lea and Eddy Counties will probably change little as a result of population increases attributable to the WIPP. First, WIPP will cause only a relatively slight increase in population. Second, many of the new residents will be working-class people with occupations much like those of residents now in the area. However, the project will bring with it some individuals having scientific or technical backgrounds not currently found in the area.

Workers in Eddy and Lea Counties probably will not benefit from the WIPP quite as much as property owners, but the difference will be relatively slight. While private wage and salary and government workers compose 90% of the employed in both counties, direct and indirect wage and salary plus all public-sector income generated by construction and operation is expected to be 87% of the total, with the remaining 13% going to property in the form of interest, dividends, and rents. (Some wage and salary workers may be the beneficiaries of increases in interest, dividends, and rents.)

Many WIPP employees, primarily miners, may be affiliated with a union. One of the several unions that represents potash and other workers in Eddy County might be expected to organize the workers, although the workers may choose to affiliate with a union new to the area. In either case, the WIPP should not change the importance of organized labor in the region.

9.4.3.2 Churches and Other Community Organizations

The influx of workers and their families will cause little increase in the number and types of churches and community organizations or in the memberships of existing organizations. The relatively small population increment is one reason. Another is that the new people, mostly blue-collar workers, will tend to join few organizations other than churches, which will probably show the greatest increases. The newcomers, if drawn from adjacent labor-market areas, will probably tend to be Baptists and fundamentalists; the large number of small churches will probably absorb virtually all of them.

9.4.4 Private Sector

Although the private sector is strong in both Lea and Eddy Counties, its economic base is rather narrow, with most economic activities centering on mining. In Lea County the oil-and-gas industry is more active than any other industrial sector; in Eddy County potash mining is the most active sector. Retail trade and services (normally nonbasic sectors) are also partly a basic industry in Eddy County because of the heavy tourism attracted by Carlsbad Caverns. Other basic industries in the area, such as agriculture and manufacturing, are substantially less active than mining.

9.4.4.1 Industrial Activity

During repository construction, certain industries in Lea and Eddy Counties are expected to become more active. Because the WIPP will need highly specialized equipment, much of the construction materials and nearly all of the technical equipment will be purchased outside the area. However, basic materials (sand and gravel, rock, certain electrical products, and concrete) can be purchased in the area. It is anticipated that construction will bring in approximately $8.4 million in new business to the manufacturing sector in the two-county area (Table 9-30).

As the project moves from construction into operation, its effect on the various economic sectors in the two-county area will change significantly. The operational phase will be similar to a warehousing operation with one important exception: the mining operations will continue.

During repository operation, the impact on local manufacturing is expected to be minimal. Examples of businesses that would experience some impact are chemicals, printing products, and machinery manufacturing. An impact may be felt indirectly in the manufacturing of food products because of increased demand. Spinoff to the industrial manufacturing system in the two-county area will be minimal.

The mining operation will also have minimal effect in attracting new industry because potash mining already dominates an extremely large portion of the economy of Eddy County. The economic impacts of the mining operation will, for the most part, flow through industries that are already established.

9.4.4.2 Trade and Services

Trade will be one of the most significantly affected sectors outside the industries receiving direct impacts. It is expected that the increase in wholesale and retail sales during repository construction will total about $48.3 million. The heaviest impact (about $18.6 million annually) will come in 1983 as employment, direct and indirect, reaches its peak. Most of this impact will be created through increased buying in the household sector. Businesses also purchase from the retail sector. However, most of the direct purchases for construction will be made from wholesale outlets. Substantial increases are also expected in the services sector, with nearly $19.7 million in new business, direct and indirect.

Table 9-30. Construction and Operations: Private Indirect Impact by Major Sector
(Millions of 1977 Dollars)

	Construction[a]										Operation (average year 1985 and after)	
	1981		1982		1983		1984		Total			
	Estimated volume	Estimated jobs	Estimated volume	Estimated jobs	Estimated volume	Estimated jobs	Estimated volume	Estimated jobs	Estimated volume	Average number of jobs	Estimated volume	Estimated jobs
Agriculture	$0.1	1.6	$0.4	5.3	$0.6	7.9	$0.4	5.4	$1.5	5.0	$0.2	2.2
Mining	0.4	3.9	1.0	8.6	1.5	12.9	1.0	7.5	3.9	8.2	0.4	1.7
Construction[b]	0.1	3.5	0.3	10.1	0.5	16.0	0.4	14.8	1.3	11.1	0.4	11.8
Manufacturing	0.7	8.7	2.1	26.9	3.2	40.7	2.4	30.0	8.4	26.6	1.3	17.6
Transportation, communications, and utilities	1.5	27.2	4.3	75.6	6.6	115.4	5.0	89.1	17.4	76.8	3.3	57.4
Trade	4.7	193.2	12.5	552.3	18.6	827.2	12.5	573.5	48.3	536.6	4.6	230.8
Finance, insurance, and real estate	1.2	43.8	3.5	130.2	5.4	201.6	4.4	162.1	14.5	134.4	2.3	85.2
Services	1.5	75.3	4.6	234.8	7.2	365.7	6.4	307.4	19.7	245.8	3.6	168.4
Total	$10.2	357.2	$28.7	1043.8	$43.6	1587.4	$32.5	1189.8	$115.0	1044.5	$16.1	575.1

[a]Includes indirect impacts from both construction and nonconstruction activities.

[b]A portion of the construction-sector impact is experienced in the finance, insurance, and real-estate sector because of the procedures followed in building the national input-output model by the Bureau of Economic Analysis, Department of Commerce. The exact impact of the portion cycled through the finance, insurance, and real-estate sector is not available.

This analysis assumes that the construction-phase demand for goods and services will take advantage of the goods and services available in the area. It also assumes that the variety of goods and services offered in the area will not change substantially during the construction period.

Beginning in 1985, repository operation will add $4.6 million annually to wholesale and retail sales in the area; this will be larger than the impact on any other identified sector. Much of it will flow into the secondary and tertiary industries rather than into the manufacturing or basic industries. The annual impact on finance, insurance, and real estate will be some $2.3 million, and the services sector will also enjoy a substantial increase, just more than $3.6 million per year.

In summary, the private-sector response to both the construction and the operation of the repository will be expressed in new activity in many of the existing secondary and tertiary industries. The operational phase will bring very few new manufacturing firms. However, small-equipment manufacturers and fabricated-metal operations may be attracted by the maintenance and construction activities during the operational phase and the need for equipment repairs.

9.4.4.3 Tourism

Certain aspects of tourism in the two-county area may be affected by the WIPP reference repository. Detailed effects are, however, difficult to define at present.

Tourism directly affects the retail trade, hotels and motels, eating and drinking establishments, service stations, and other trade and service subsectors. To a lesser degree, it also influences certain government operations (e.g., those of the National Park Service) and some manufacturing activities (such as curios and jewelry).

Tourism in the two-county area centers around the caverns in the Carlsbad National Park, 18 miles southwest of Carlsbad. Carlsbad National Park is a unique attraction, one not likely to lose its popularity because of the repository. Other areas, such as the Living Desert State Park just west of Carlsbad, offer a variety of recreational opportunities but do not attract many tourists from outside the region.

The existence of nuclear-weapons laboratories and atomic-energy research establishments in New Mexico has not hindered tourism. A prime example is the city of Los Alamos, the site of the Los Alamos Scientific Laboratory. Tourism in Santa Fe, only 40 miles away, has continued to increase, and Los Alamos itself has become a point of interest. Thus past experience indicates that the WIPP will exert no significant adverse impacts on tourism over an extended period.

There may, however, be some short-term impacts on hotels, motels, and other services and facilities serving tourists. As construction proceeds, a number of transient construction workers will locate in the area. Many are expected to live in temporary quarters for short periods. Past experience

reveals that many construction workers stay in camping trailers, campers, or camping mobile homes owned by concession companies during the work week and travel home for weekends; others may stay in motels and hotels. The transient workers may therefore decrease the overnight facilities available to tourists. This impact is likely to last only 1 to 2 years. During operation this impact is not likely since temporary housing facilities will not be affected to any degree.

9.4.5 Housing and Land Use

9.4.5.1 Total Housing Requirements of the WIPP Reference Repository

The total demand for housing for population migration directly or indirectly induced by the WIPP in Eddy and Lea Counties is indicated in Table 9-31. Housing demand peaks in 1983 with 1190 total housing units and decreases to 420 total units in 1986 and thereafter.

The composition of housing demand (Old West Regional Commission, 1975) is expected to change as construction ends and operation begins. During construction, there is likely to be a relatively large demand for mobile homes and multifamily units; during operation, 70% of the demand will be for single-family units.

Table 9-31. Total Housing Demand Induced by the WIPP Reference Repository

Year	Total[a]	Permanent single family[b]	Permanent multifamily[b]	Mobile homes and others[b]
1981	250	140	20	90
1982	720	410	70	240
1983	1190	700	120	370
1984	1010	630	100	360
1985	540	380	60	100
1986	420	300	50	80
1987	420	300	50	80
2000	420	300	50	80

[a]Total housing demand based on population migration projections resulting from direct and indirect jobs (Table 9-29). Detail does not sum to total because of rounding.

[b]Allocation of total demand to housing types based on housing preferences of construction workers and other newcomers in Construction Worker Profile (Old West Regional Commission, 1975).

9.4.5.2 Scenario I: Carlsbad

Housing

According to Table 9-32, the projected baseline-population increases for Carlsbad call for an addition of at least 1130 housing units from the end of 1977 through mid-1981; this figure, which would drop the vacancy rate to zero, comes from subtracting the total housing stock at the end of 1977 (9420) from the occupied housing in mid-1981 (10,550). When added to the current total of 34 substandard units not suitable for rehabilitation, this means an increase of about 1160 units over the 3.5 years, or an average of about 330 units per year--somewhat less than the rate of construction in 1977.

Planned housing construction for the 4 years from 1978 through 1981 calls for somewhere between 1650 and 1750 new units. The exact timing of these new units is not known, but it appears that construction will keep pace with projected demand and may even exceed it.

In order to bring the vacancy rate up to 3% by mid-1981 and to replace the 34 substandard units, a total of 1480 units must be added over the 3.5-year period (Table 9-32). This is an average of 425 units per year, somewhat over the recent rate; however, it is slightly below the 438 units per year planned for the 1978-81 period. It thus appears that, if planned construction rates are continued into 1981, addition to the housing stock will be sufficient to bring the total housing stock to a level providing a 3% vacancy rate.

Baseline population projections for the period from 1981 to 1985 call for 1030 new housing units, or 258 per year. The next 2 years are projected to show an increase in housing demand of 560 units, or 280 per year. Maintaining a 3% vacancy rate over the 1981-87 period would require an additional 1650 units, or 275 per year. Thus, it appears that the relatively rapid pace of construction projected into 1982 should slow somewhat during the mid-1980s under baseline conditions.

Population projections with the WIPP increase housing demand for the 1980-84 period to 2020 units, or 505 per year. The primary impact of the WIPP, however, is in the year from mid-1981 to mid-1982: Housing demand will increase by 820 units over the year versus 420 units under baseline conditions. Moreover, much of the increase will be fairly sudden, occurring soon after the start of construction. It would appear that a housing shortage may develop in 1981 or 1982 (if scenario I conditions prevail).

There are three factors that may mitigate the shortage, however. First, as noted above, it is possible that current plans for construction for the period 1978-82 may result in some overbuilding in comparison to baseline housing demand. The resulting carryover would lessen demand for new construction in 1982. Second, a relatively large share of construction workers tend to prefer mobile homes (Table 9-33). Third, construction workers are highly mobile. Construction activity can be expanded more rapidly than most other industrial activity. In fact, the sudden increase in housing demand is itself a result of the assumption that the level of construction activity on the project can be rapidly expanded.

Table 9-32. Housing Demand: Scenario I, Carlsbad

Year	Occupied housing		Change from previous year		Occupied housing plus 3% vacancy rate		Change from previous year	
	Baseline	With WIPP	Baseline	With WIPP	Baseline	With WIPP	Baseline	With WIPP
1977	9,320[a]	--	--	--	9,420[b]	--	--	--
1978[c]	9,580	--	260[d]	--	9,970	--	550[d]	--
1979	9,880	--	300	--	10,190	--	220	--
1980	10,230	--	350	--	10,570	--	380	--
1981[e]	10,550	10,760	320	530	10,870	11,100	300	530
1982	10,970	11,580	420	820	11,310	11,940	440	840
1983	11,160	12,160	190	580	11,500	12,540	190	600
1984	11,400	12,250	240	90	11,760	12,630	260	90
1985	11,580	12,030	180	(220)	11,940	12,400	180	(230)
1986	11,860	12,220	280	190	12,230	12,600	290	200
1987	12,140	12,500	280	280	12,520	12,890	290	290

[a]Estimated year-end occupied units.

[b]Actual year-end housing stock, based on U.S. Department of Commerce, 1970 Census of Housing, and subsequent building-permit and demolition data for Carlsbad.

[c]Figures for 1978 and subsequent years are mid-year.

[d]Six-month change.

[e]Beginning year of construction. Impact assumed to be static after 1986.

Table 9-33. Repository-Induced Housing Demand by Type: Scenario I, Carlsbad[a]

Year	Total	Permanent single family	Permanent multifamily	Mobile homes and other
1981	220	120	20	80
1982	610	340	60	200
1983	1010	580	100	320
1984	850	530	90	230
1985	450	320	50	80
1986	360	250	40	60
1987	360	250	40	60

[a]Detail does not equal total because of rounding. Allocation of total demand to housing types based on the housing preferences of construction workers and other newcomers in Construction Worker Profile (Old West Regional Commission, 1975).

It is impossible to predict the extent to which these factors will mitigate the housing shortage at the start of repository construction. It appears that there will be some shortage, however, with an associated increase in rents and housing prices. Whatever shortage does develop, it is not likely to persist beyond the end of construction. The total demand is actually less in 1985 and 1986 than in 1984, and the cumulative demand from 1980 to 1985 can be met at an annual rate of 360 units. This is less than the rate expected between 1978 and 1981.

Land use

If the housing-demand estimates in this section are correct and if the average lot size for new housing units is estimated generously at 0.25 acre, about 200 acres will be required for new residential development from the start of 1978 through mid-1980. From 1980 through 1987, an additional 478 acres will be needed under baseline conditions. When compared with the present vacant area of about 7500 acres, this 8-year cumulative demand of 678 acres clearly leaves an ample surplus for commercial and industrial development as well as parks, streets, and other land uses.

If the WIPP reference repository is begun in 1981, an additional 568 acres will be required for residential development through 1987, bringing the 8-year cumulative demand to 768 acres. Given the availability of vacant land, the implementation of the project does not appear likely to cause any land-use problems in Carlsbad.

9.4.5.3 Scenario II: Hobbs

Housing

According to Table 9-34, the projected baseline-population increases for Hobbs call for an addition of at least 410 housing units from the end of 1977 through mid-1980; this figure, which would drop the vacancy rate to zero, comes from subtracting the total housing stock at the end of 1977 (10,880) from the occupied housing in mid-1980 (11,290). This represents an annual rate of about 165 units for the 2.5-year period, or about 27% of the record addition of more than 600 units in 1977.

In order to maintain a 3% vacancy rate in mid-1980, about 760 units will be needed, or 304 per year. Under baseline conditions, 2670 new housing units will be needed from 1980 through 1987, or about 380 per year, a rate well below that for 1977.

The WIPP reference repository would increase cumulative 1980-87 requirements by 150 units, bringing the annual rate up to 403 units for the 7 years: the same rate as that achieved in 1976 and only two-thirds the rate maintained in 1977. Thus it does not appear that there will be any difficulty in providing projected new-housing requirements through 1987, with or without the WIPP.

Table 9-35 indicates WIPP-induced housing demand by type. The pattern is the same as that projected for Carlsbad, with preference for mobile homes and multifamily units during construction and for single-family units during operation.

Land use

Using the present average lot size of one-seventh of an acre, projected cumulative housing additions through 1987 would require about 440 acres under baseline conditions and about 460 acres with the WIPP. However, if the lot size of newer homes is one-quarter acre, 770 acres will be required without, and 808 acres with, the WIPP.

Not including land in the Hobbs Industrial Air Park, there are an estimated 960 acres of vacant land within the current Hobbs city limits, primarily in the north end of town. Thus there is more vacant land than will be required for the new housing units alone. There is some question, however, about the ability of the vacant area to accommodate new housing and additional commercial and public development. Currently, there is an average of 1.25 occupied acres for every housing unit in Hobbs. If this average acreage is to be maintained, projected housing additions (3250 units)* will require about 4000 acres, or more than four times the available vacant area. While it is not suggested that actual nonresidential land requirements grow in direct proportion to those for residential purposes, it is probable that some of the currently vacant land will be used for nonresidential purposes. As a result, it is possible that there will be little or no vacant land remaining within the current city limits of Hobbs by the late 1980s.

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*For 1978 to mid-1981, 800 housing units; for mid-1981 to mid-1987, 2300 (baseline) plus 150 because of the WIPP repository.

Table 9-34. Housing Demand: Scenario II, Hobbs

Year	Occupied housing		Change from previous year		Occupied housing plus 3% vacancy rate		Change from previous year	
	Baseline	With WIPP	Baseline	With WIPP	Baseline	With WIPP	Baseline	With WIPP
1977	10,660[a]	--	--	--	10,880[b]	--	--	--
1978[c]	10,860	--	200[d]	--	11,200	--	320[d]	--
1979	11,100	--	240	--	11,450	--	250	--
1980	11,290	--	190	--	11,640	--	190	--
1981[e]	11,660	11,750	370	460	12,020	12,110	380	470
1982	11,980	12,240	320	490	12,360	12,620	340	510
1983	12,360	12,780	380	540	12,740	13,180	380	560
1984	12,720	13,090	360	310	13,120	13,490	380	310
1985	13,120	13,320	400	230	13,530	13,730	410	240
1986	13,520	13,670	400	350	13,930	14,090	400	360
1987	13,960	14,110	440	440	14,390	14,550	460	460

[a]Estimated year-end occupied units.

[b]Actual year-end housing stock, City of Hobbs Housing Count, 1978.

[c]Figures for 1978 and subsequent years are mid-year.

[d]Six-month change.

[e]Beginning year of construction. Impact assumed to be static after 1986.

Table 9-35. Repository-Induced Housing Demand by Type: Scenario II, Hobbs[a]

Year	Total	Permanent Single family	Permanent Multifamily	Mobile homes and other
1981	90	50	10	30
1982	260	150	30	80
1983	430	250	40	130
1984	360	230	40	100
1985	200	140	20	40
1986	150	110	20	30
1987	150	110	20	30

[a]Detail may not equal total because of rounding. Allocation of total demand to housing types based on housing preferences of construction workers and other newcomers in Construction Worker Profile (Old West Regional Commission, 1975).

To some extent, this increasing scarcity of land may cause some of the housing development projected for Hobbs to take place outside the city limits. This, in turn, may prompt expansion of the city limits, an action that must be instigated by petition from the residents or landowners in the annexed area. Any development outside the current city limits will most likely take place to the north of Hobbs. Land to the east and south of the city is owned by three individuals who are currently unwilling to sell, while the west is constrained by oil- and gas-field developments.

9.4.6 Community Services and Facilities

9.4.6.1 Scenario I: Carlsbad and Eddy County

Education-Carlsbad School District

Projections of school enrollments indicate that excess physical capacity will continue to characterize the Carlsbad school system. The 1986-87 school year enrollment will require only about 80% of the available classroom space (Table 9-36). Overall, the student population should increase by about 25% during the decade from 1976-77 to 1986-87.

The principal effect of the WIPP will be to accelerate the rate of increase in enrollment, with a 25% increase being reached by the 1983-84 school year (Table 9-36). The 10-year increase is projected to be 28%. This accelerated rate of student-population growth however, will not tax the capacity of the school system. The 1986-87 enrollment level with the WIPP will require about 85% of the current classroom space.

Increased enrollments may require additional teachers, although it is possible to allow the student-teacher ratio to rise. Maintaining the current student-teacher ratio would require about 76 additional teachers under baseline conditions by 1986-87 and about 87 with the project. Administrative and

Table 9-36. Current and Projected Enrollments in the Carlsbad School District[a]

Year	Grade K-6[b]	6-8	9-10	11-12	Total
		ENROLLMENT CAPACITY			
	4600	1860	1770	1870	10,000
		BASELINE			
1976-77[c]	3111	1315	1229	1042	6697
1977-78[c]	3178	1390	1132	1037	6737
1981-82	3550	1550	1270	1160	7530
1982-83	3630	1590	1290	1190	7700
1983-84	3700	1600	1320	1210	7830
1984-85	3760	1640	1340	1220	7960
1985-86	3840	1680	1370	1250	8140
1986-87	3930	1710	1400	1280	8330
		WIPP SCENARIO I			
1981-82[d]	3660	1600	1310	1200	7760
1982-83	3850	1680	1360	1260	8160
1983-84	3960	1710	1410	1300	8370
1984-85	3950	1720	1400	1280	8360
1985-86	3960	1740	1420	1290	8400
1986-87	4040	1760	1440	1320	8560

[a]Detail may not equal total because of rounding.
[b]Includes special education; kindergarten students counted as full time.
[c]Carlsbad 40-day average daily membership reports.
[d]Start of construction.

staff personnel requirements will probably also grow, but not necessarily as rapidly as enrollment. Because enrollments with the project are projected to be only marginally larger than those without the project, they may not result in any increase in demand for administrative and staff personnel.

During the 1977-78 school year, the Carlsbad school district reopened an elementary school in the south portion of the city, an area of high potential population growth. Thus a potential school shortage in that part of the city has been alleviated.

It appears that the WIPP repository is not likely to cause any overlapping problems at any grade level in the Carlsbad school system.

Groundwater and municipal water system

Carlsbad has sufficient water rights for the next several decades but has an immediate need for a delivery system with access to those rights. Table

9-37 contains projected withdrawals and depletions* for Carlsbad without the WIPP project. Baseline withdrawals are expected to rise from the 1977 level of 8800 acre-feet to 10,950 by 1987 and 13,250 by 2000. Implementation of the project would increase demand by as much as 8% during construction and 3% in subsequent years.

The city presently has rights to 27,121 acre-feet per year and is negotiating the purchase of 258 additional acre-feet per year. Combined demand for 1978 and 1979 is projected to be 18,300 acre-feet. In addition, the Capitan reef payback calls for 2200 acre-feet over the 2-year period, which yields a total claim on Capitan reef rights of 20,500 acre-feet. Assuming that the 258 acre-feet currently being negotiated are transferred to the well field, combined rights in the Capitan reef for 1978-79 are 18,182, resulting in a cumulative shortfall of 2318 acre-feet. As shown in Table 9-38, without an additional delivery system this overpumping would continue to worsen, and the WIPP reference repository would exacerbate the problem.

The excess-demand problem can be quickly corrected, however. A pipeline from the Double Eagle system with a capacity of 3200 acre-feet per year is currently in the development stage. If this pipeline becomes operational at the start of 1982, previous overpumping could be repaid by mid-1983 under baseline conditions. If the WIPP project is implemented, the payback period will be extended for a few months.

With the addition of 3200 acre-feet per year, the system capacity should be sufficient to meet demands (including peak load) until nearly 2000. The implementation of the WIPP would shorten this time by a few months.

It appears that in the long run Carlsbad has ample water rights to meet anticipated demands with or without the WIPP. The Double Eagle pipeline will provide a delivery system that is adequate until about the year 2000, with or without the WIPP. At present, the delivery system does not provide access to sufficient water rights. Without the Double Eagle pipeline, the situation will get worse--the more so if WIPP is implemented.

Municipal wastewater systems and treatment facilities

The new sewage-treatment plant, now in the design phase, will be capable of serving a population of 50,000. Because its design capacity is well over projected population levels (with or without the WIPP) through the end of this century, the new plant should be adequate for the needs of Carlsbad for the next several decades.

The present sewer system will have to be extended into areas of new housing development. Moreover, population increases will result in increased wastewater flows through existing main sewer lines. City officials have indicated that the existing main sewer lines can handle projected increases (with or without the WIPP) through the year 2000.

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*The term "depletion" refers to that part of the water withdrawn that is no longer available because it has been evaporated, transpired, incorporated into products or crops, consumed by man or livestock, or otherwise removed from the water environment.

Table 9-37. Water Demand in Carlsbad[a] (acre-feet per year)

Year	Baseline		With WIPP	
	Withdrawals	Depletions	Withdrawals	Depletions
1970	7,100[b]	3500[b]		
1977	8,800[c]	5000[d]		
1978	9,100[d]	5250		
1979	9,200	5400		
1980	9,400	5600		
1981[e]	9,600	5800	9,750	5900
1982	9,950	6050	10,450	6350
1983	10,050	6100	10,850	6600
1984	10,250	6250	11,000	6700
1985	10,450	6400	10,850	6650
1986	10,700	6600	11,000	6800
1987	10,950	6800	11,250	7000
2000	13,250	8650	13,600	8900

[a]Peak load in 1977, 16 mgd; in the year 2000: baseline, 24 mgd; with WIPP, 25 mgd.

[b]New Mexico Interstate Stream Commission and New Mexico State Engineer's Office (1975); County Profile, Eddy County.

[c]City Manager's Office, Carlsbad, New Mexico.

[d]Based on population projections made in this study and per capita withdrawal and depletion projections by the New Mexico Interstate Stream Commission, op. cit., adjusted for actual 1977 withdrawals.

[e]Start of construction.

Table 9-38. Cumulative Excess Water Demand (acre-feet per year)

Year	Present system[a]		With Double Eagle[b]	
	Baseline	With WIPP	Baseline	With WIPP
1978	2,209			
1979	2,318			
1980	2,627			
1981[c]	3,136	3,286		
1982	3,995	4,645	795	1445
1983	4,954	6,404	-1446	4
1984	6,113	8,313		
1985	7,472	10,072		-1287
1986	9,081	11,981		
1987	10,950	14,140		

[a]Rights to 8833 acre-feet per year plus 258 acre-feet per year, for a total of 9091 acre-feet per year.

[b]Double Eagle pipeline (capacity 3200 acre-feet per year) assumed to begin operation on January 1, 1982, raising the total capacity to 12,291 acre-feet per year.

[c]Start of construction.

Electric service

Projected occupied-housing additions to the Carlsbad area under baseline conditions total 2820 from 1978 through mid-1987. By mid-1987, this will result in a 6.7% increase in total energy use in the area over current levels if current rates of use continue. Moreover, new commercial hookups will be required by the end of 1986, causing an additional increase in energy use of 6.4% over current levels.

The WIPP project will result in the addition of about 3180 new housing units between 1978 and 1987, resulting in a 7.5% increase in energy use. Commercial use would add about 7.2%. The net effect of the repository would be to increase residential and commercial energy use by about 3.0% by mid-1987. Total energy use would be up about 1.3% as a result.

The WIPP itself will require as much energy as many of the large industrial users in the area. Its demand level will be about one-tenth that of an area ammonia plant that recently closed. The closing of the ammonia plant in effect created excess electrical supply capacity sufficient to cover about 10 times the projected WIPP demand.

According to Southwestern Public Service Company officials, the generating capacity will be sufficient to meet the projected energy demand. However, new distribution substations will be required, and there is a lead time of 3 to 6 months for new hookups.

Natural gas service

Projected housing demands through 1987 in the Carlsbad area under baseline conditions predict that residential hookups will increase 30% over current levels. At current consumption rates, this will increase natural gas consumption by 3.4%. Increased commercial use will raise consumption an additional 1.5%.

The WIPP will increase the residential consumption of natural gas by 3.9%. Commercial use will rise 1.7% above current levels by the end of 1987. As a result of the WIPP, gas consumption will be about 0.5% above baseline levels in 1987.

Gas Company of New Mexico officials believe that these increases, with or without the WIPP project, can be met without difficulty.

Fire protection

To maintain current levels of fire protection in 1987, Carlsbad will need 27 full-time fire-department employees under baseline conditions and 28 employees with the WIPP. These are increases of five and six employees, respectively, from the current 1978 level. One additional piece of major equipment will be needed in 1987 without the WIPP and two additional pieces with the project. Without the project, the one airport and two nonairport substations will provide sufficient coverage in 1987. However, the growth of the city with the WIPP will require an additional fire substation by 1987. The principal impact of the WIPP will thus be to require additional personnel and equipment at an earlier date.

Police protection

Under baseline conditions the number of police employees will have to increase from 40 to 49 in 1987 in order to maintain the current ratio of police employees to city inhabitants. The WIPP reference repository will create the need for two more police employees (a total of 51 in 1987). Five additional Eddy County Sheriff employees will be needed in 1987. The WIPP is not expected to create any conditions that would significantly change the required number of Sheriff's Department employees. The implementation of the WIPP will change the times when additions to the police and sheriff's departments are needed.

Health care

To maintain current service levels, Eddy County will require 192 hospital beds by mid-1987 under baseline conditions and 196 with the WIPP. If occupancy rates are allowed to rise over current levels and if per-capita demand for hospital beds remains unchanged, the 1987 baseline county population can be accommodated with about 143 beds. With the WIPP, about three more beds will be required. The resulting increase in occupancy rates would bring countywide occupancy to about 88% (90% with the WIPP). Thus, current hospital facilities appear to be adequate to meet demand through the 1980s if occupancy rates are allowed to rise. Moreover, the Guadalupe Medical Center has several double rooms that currently contain only one bed. The number of beds can therefore be increased fairly readily, bringing occupancy rates down.

The number of primary-care physicians required at current service levels will be 23.5 by mid-1987 under baseline conditions and 24 with the WIPP. This would leave the physician-to-population level below that recommended by Bennett (1977). Using Bennett's standard of one primary-care physician to 1200 people, the WIPP would increase the demand for primary-care physicians by about one. In general, the WIPP-related demand for area medical personnel will increase in approximate proportion to the WIPP-induced population change (about 2% in 1987).

Projected population levels for 1987 call for one additional ambulance under baseline levels. The WIPP should not add to this requirement.

Traffic and transportation

Access to the site will be provided by a road connecting the site to U.S. 62-180 to the north. Also planned is a road to the south connecting with N.M. 128; however, main traffic flow is expected to be from the north. There may be temporary minor disruption of traffic on U.S. 62-180 and N.M. 128 while the access roads are being connected. Site construction itself will be several miles off the public roads and should therefore cause no disruption of traffic flows or patterns.

During construction and operation, there will be some increase in traffic on U.S. 62-180 between the site access road and Carlsbad. However, since present plans call for some workers to be bused to the site during both phases, the traffic-volume increase will be minimal. Since U.S. 62-180 is a four-lane highway, slow-moving buses will not impede other traffic.

Figure 9-7 indicates 1976 traffic volume for selected locations in Carlsbad. Table 9-39 presents peak traffic flows and street capacities for several of these locations. Currently, traffic flows are well within the existing capacity of the street system (New Mexico Highway Department, 1976).

Projections of 1987 peak traffic flows are also presented in Table 9-39; they are based only on projected population increases, with and without the WIPP, and not on the location of new housing developments. The only location where capacity is reached or exceeded is site B on Canal Street. This is in the downtown business district, and the population-based projection is probably reasonably accurate. The other sites are feeder routes from expected new population centers to the downtown area. They are thus likely to receive impacts greater than those indicated in Table 9-39. Most, however, have considerable excess capacity.

On a subjective basis, it appears that the location of new housing will cause the most severe impact on San Jose Boulevard and Boyd Drive. (No traffic counts are available for Boyd Drive.) The extent of the impact is impossible to predict, however, since it depends primarily on the location of the place of work of residents in new homes. (For those working in the potash mines or at the site, it depends on the location of bus pickup points.) The place of work is of primary importance since about 50% of all trips with origins or destinations in Carlsbad is for work purposes.

Communication services and facilities

Under baseline conditions, by 1988 the number of telephone main stations in service will increase by about 3700, or about 30% over the 1977 year-end level. With implementation of the WIPP reference repository, the increase will be about 4200, or 34%. As a result, the net effect of the WIPP will be to raise the demand for telephone service about 3% above baseline levels.

General Telephone of the Southwest is anticipating completion of a new central office with automated switching in late 1979 or early 1980. Company officials state that this facility will provide ample capacity to meet projected demands with or without the WIPP.

Recreation

Quantitative measurement of impact on most community recreation facilities is difficult, if not impossible, for several reasons. First, recreation, particularly outdoor recreation, occurs over a geographic area much larger than the city limits. Second, measurements for determining capacity and impact are made by the State of New Mexico in conjunction with the Bureau of Outdoor Recreation, an agency of the U.S. Department of the Interior. Information from these two agencies is limited to multicounty areas known as Recreational Market Areas (RMAs). Third, people who migrate to the area may not have the same recreational values as those who already live there.

The New Mexico State Planning Office defines seven RMAs, with RMA 6 covering the counties of Chaves, Eddy, Lea, Lincoln, and Otero. Analysis of recreational facilities and use patterns for this RMA indicates that facilities for two popular outdoor recreational activities, camping and pool swimming, will be insufficient by 1985 if present capacities are not increased.

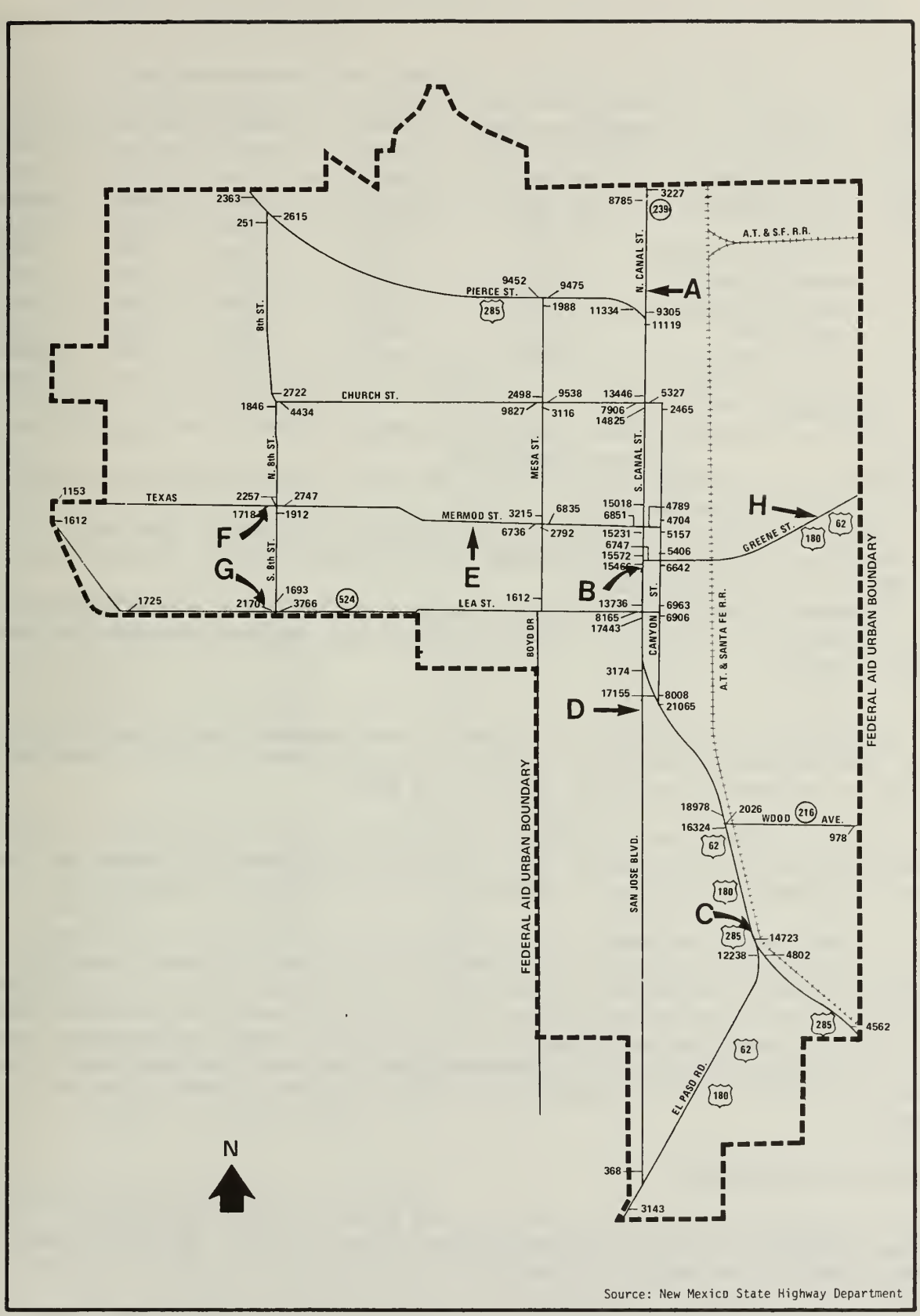


Figure 9-7. Carlsbad average daily traffic, 1976.

Table 9-39. Selected Traffic Flows and Road Capacities, Carlsbad

Site[a]	Street	Average daily traffic, 1976[b]	Peak hour (4-5 p.m.) 1976[c]	Projected peak hour, 1987[d] Baseline	Projected peak hour, 1987[d] WIPP	Peak-hour capacity[e]
A	Canal Street	9,305	850	1150	1180	1900
B	Canal Street	15,466	1410	1900	1960	1900
C	U.S. 285	14,723	1340	1810	1860	2900
D	San Jose Boulevard	3,174	290	390	400	950
E	Mermod Street	6,736	610	820	850	1900
F	Texas Street	1,718	160	220	220	950
G	Lea Street	2,170	200	270	280	950
H	U.S. 62-180	4,890	440	590	690[f]	2900

[a]See Figure 9-7.

[b]New Mexico State Highway Department (1976), Traffic Flow Maps of Urban Areas.

[c]Based on percentage hourly loads, New Mexico State Highway Department (1969), Carlsbad Traffic Study.

[d]Assumes increase in proportion to population increase. See text.

[e]Based on street-capacity estimating procedures used by the Middle Rio Grande Council of Governments.

[f]Assuming travel from the site is during the peak hour and an average of two occupants per vehicle. Comparable figure for the peak construction year (1983) is 900.

Popular RMA activities that appear to have adequate facilities through the year 2000, given the population growth with and without the WIPP, are fishing (lake and stream), picnicking, tennis, and golf.

Demand for new swimming pools in Carlsbad is likely to develop in the next few years. The city currently has an adequate supply of city parks and recreational facilities in the Presidents' Park-Carlsbad Lake complex.

Indoor recreational activities are generally sponsored by the private sector. One major exception is recreation for senior citizens. The City of Carlsbad already provides a program to meet this demand, and it is expected that the WIPP reference repository will not significantly increase the demand in this category. Moreover, since the overall WIPP impact on the population of Carlsbad is only about 8% of the total population in the peak impact year (1983), no significant problems with indoor recreational facilities are expected.

Solid-waste management

The projected baseline increase in the population indicates that two additional vehicles will be needed to collect refuse in 1987. With the repository, almost three additional vehicles will be needed in 1987.

The present Carlsbad landfill is expected to be filled in 1988. With the WIPP project, the present landfill will reach capacity 2 months earlier.

9.4.6.2 Scenario II: Hobbs and Lea County

Education--Hobbs School District

School-enrollment projections indicate that the Hobbs municipal schools may experience crowding in all grades by the early to mid-1980s (Table 9-40). Under baseline conditions, the average class will exceed 24 students in the 1983-84 school year. Under the assumptions of scenario II, this increase in class size will happen 1 year earlier. By the 1986-87 school year, the average class will have more than 26 students under baseline conditions and somewhat more students with the WIPP.

Table 9-40. Projected Enrollments for the Hobbs School District

Year	Grade K-6	Grade 7-9	Grade 10-12	Total
		ENROLLMENT CAPACITY[a]		
	4630	1990	1730	8350
		BASELINE		
1978-79[b]	4195	1765	1715	7675
1981-82	4440	1870	1810	8120
1982-83	4540	1910	1850	8300
1983-84	4650	1960	1900	8510
1984-85	4770	2000	1940	8710
1985-86	4870	2050	1990	8910
1986-87	4990	2100	2030	9120
		WIPP SCENARIO II		
1981-82[c]	4500	1900	1830	8220
1982-83	4640	1960	1890	8490
1983-84	4780	2020	1950	8740
1984-85	4860	2040	1980	8880
1985-86	4930	2080	2020	9020
1986-87	5040	2120	2050	9210

[a]Estimated capacity, assuming 24 students per classroom.
[b]Ray Wasson, Assistant Superintendent for Personnel, Hobbs Municipal Schools, letter, May 22, 1978.
[c]Start of construction.

Groundwater and municipal water system

With rights to just more than 18,000 acre feet per year (Herkenhoff, 1976), Hobbs has sufficient water rights to cover anticipated demand until well past the year 2000. As shown in Table 9-41, withdrawals will be slightly more than 12,000 acre-feet in 2000 under baseline conditions. With the implementation

Table 9-41. Water Demand in Hobbs[a] (acre-feet per year)

Year	Baseline		With WIPP	
	Withdrawals	Depletions	Withdrawals	Depletions
1970[b]	6,800	3100		
1977[c]	6,950	3850		
1978	7,050	4050		
1979	7,150	4200		
1980	7,300	4350		
1981[d]	7,500	4550	7,550	4550
1982	7,700	4650	7,800	4750
1983	7,900	4800	8,150	4950
1984	8,150	4950	8,350	5100
1985	8,350	5100	8,450	5150
1986	8,600	5300	8,650	5350
1987	8,850	5450	8,950	5500
2000	12,000	7800	12,100	7850

[a]Peak day (based on peak-day factors (Herkenhoff, 1976)), in 1977, 13,640,000 gallons; in the year 2000: baseline, 23,886,000 gallons; with WIPP 24,190,000 gallons.

[b]New Mexico Interstate Stream Commission and New Mexico State Engineer's Office (1975); County Profile, Lea County.

[c]Estimates based on population projections by this study and per capita withdrawal and depletion projections by the New Mexico Interstate Stream Commission, op. cit., adjusted for recent water-rate increase.

[d]Start of construction.

of WIPP, an additional 100 acre-feet will be required that year. The greatest impact will occur in 1983, with an additional demand of 250 acre-feet per year.

Although water rights are adequate for several decades, the 14-mgd current yield of the 23 existing wells is only slightly greater than the current peak-day demand. Peak-day demand is projected to exceed existing well yields in 1980, before the start of construction. Unless additional wells are brought into production, there may be some temporary water shortages in mid-summer of 1980, with the shortages becoming worse in succeeding summers. Implementation of the WIPP project would increase the shortfall somewhat.

Municipal wastewater systems and treatment facilities

With an anticipated wastewater flow of 79.5 gallons per capita per day, an average of 3 mgd of wastewater will be generated in 1985 under baseline conditions. By 1990 this will rise to 3.4 mgd. With the WIPP, wastewater flows will reach 3.06 mgd in 1985 and 3.47 mgd in 1990. Since the capacity of the sewage-treatment plant under construction is about 5 mgd, with expansion to 6 mgd possible, there should be no problems with sewage-treatment facilities, with or without the WIPP, for the next several decades.

New main sewer lines, replacing or supplementing several existing main lines, will provide service from the north side of town, the area of anticipated population growth, to the sewage-treatment plant on the south side of town. As a result, no problems should be experienced in delivering wastewater to the treatment plant, with or without the WIPP.

The foregoing analysis assumes that all projected population increases in Hobbs actually occur within the city limits. However, as indicated in Section 9.4.5.3, there is a high probability that current city limits will be unable to accommodate all of the projected population increase. In fact, much of the recent growth in the Hobbs area has taken place outside the city limits to the north. If future growth does occur in this area and the new housing units are not connected to the municipal sewer system, it will be necessary to use septic systems. Since conventional septic systems have presented problems with seepage into groundwater, it is necessary to use the somewhat more expensive evapotranspiration systems. This, in turn, will mean a slight increase in housing costs.

Electric service

By mid-1987, residential energy consumption will increase by 4.2% over 1977 year-end levels, with 0.2% attributable to the WIPP. If the current ratio of commercial to residential use is maintained, commercial use will require an additional 4%, of which 0.2% will be induced by the WIPP. The net effect of WIPP-induced residential and commercial energy use will be an increase of 0.25%.

Natural gas service

With the implementation of the WIPP reference repository, 2980 new residential connections and 390 commercial hookups will be required through mid-1987. Demand for natural gas by these two sectors will rise by 32.3%. The net impact of the WIPP will be to cause an increase of 1.0% in residential and commercial natural gas use. According to Hobbs Gas Company officials, provision of the projected expansion of service, with or without the WIPP project, will not be a problem.

Fire protection

Without the WIPP, the Hobbs fire department will have to increase from 44 employees in 1978 to 54 in 1987 in order to maintain the current ratioof fire-department employees to city inhabitants. The WIPP is expected to increase the number of employees by one. By 1987 the number of major fire-equipment units and substations will have to increase by 2 and 1, respectively, if the current level of fire protection is to be maintained. The WIPP is not expected to alter that projected increase significantly.

Police protection

An additional 18 police employees, an increase of 22%, will be needed in Hobbs by 1987 under baseline conditions, in order to maintain the current level of service. With the implementation of the WIPP, the added employee requirement would be 19, an impact of 1 employee by 1987.

Under baseline conditions, the Lea County Sheriff's department will need an additional six employees. With the WIPP project, the needed increase is expected to be one additional employee.

Health care

Projected population increases for Lea County to mid-1987 will increase the requirements for hospital beds to 110 under baseline conditions and current use rates. With the WIPP, the demand would rise to 111. Occupancy rates would rise to about 61 and 62%, respectively, well below the recommended level of 80% (Bennett, 1977).

Medical-personnel requirements in 1987 will be about 1% greater with the WIPP than without. If current levels of primary-care physician to population are maintained, this means an increase of 0.3 physician due to WIPP. If the standard proposed by Bennett is used, WIPP-induced population change in 1987 will result in the need for 0.5 extra primary-care physician. Overall, the WIPP will raise personnel requirements by less than 1% and will not increase capital facility requirements measurably. Ambulance requirements will rise to five vehicles under baseline or WIPP conditions.

Traffic and transportation

Access to the site from Hobbs would be on U.S. 62-180. Since this highway is well below peak-hour capacity, commuting by WIPP employees is not expected to have any significant impact. These projections are based on projected increases in population, with or without the WIPP, and should provide reasonably accurate results for the intracity traffic flows.

Figure 9-8 indicates selected 1976 traffic flows for several locations in Hobbs. Table 9-42 presents peak traffic flows and street capacities for several of these locations.

Table 9-42. Selected Traffic Flows and Road Capacities, Hobbs

Site[a]	Street	Average daily traffic 1976[b]	Peak-hour traffic 1976[c]	Project peak hour, 1978[d]		Peak-hour capacity[e]
				Baseline	WIPP	
A	Turner	10,829	1083	1380	1400	2900
B	Grimes	11,035	1104	1410	1420	1900
C	Dal Paso	14,135	1414	1810	1830	1900
D	Bender	12,325	1232	1570	1590	1900
E	Turner	14,765	1476	1890	1910	1900
F	Dal Paso	15,239	1524	1950	1970	1900
G	Broadway	11,032	1103	1410	1420	1900
H	U.S. 62-180	5,909	591	760	800[f]	1900

[a]See Figure 9-8.

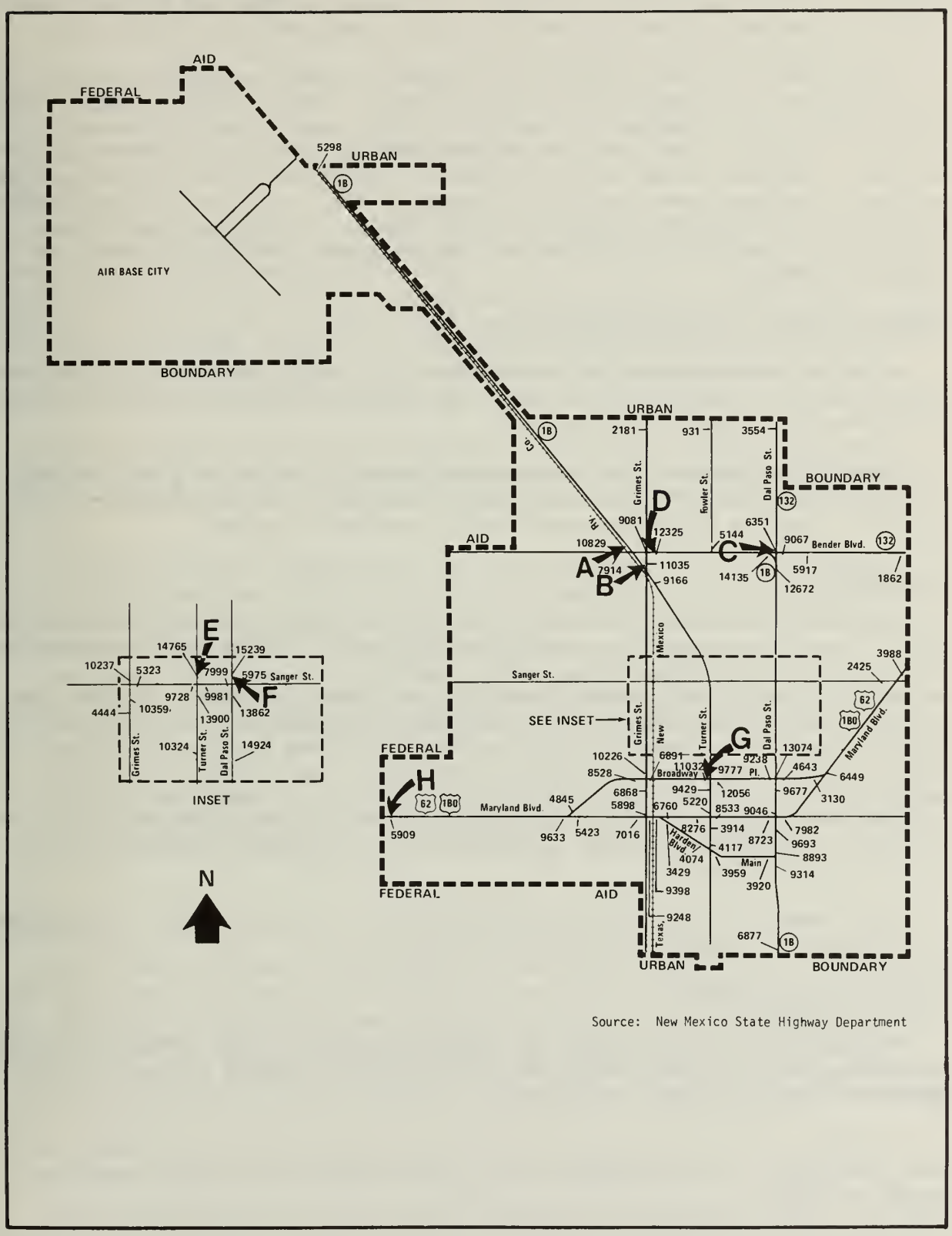
[b]New Mexico State Highway Department (1976), Traffic Flow Maps of Urban Areas.

[c]Assumed to be 10% of the average daily traffic flow.

[d]Assumes increase in proportion to population increase. See text.

[e]Based on street-capacity estimating procedures used by the Middle Rio Grande Council of Governments.

[f]Assuming travel from the site is during the peak hours and an average of two occupants per vehicle. Comparable figure for the peak construction year (1983) is 830.



Source: New Mexico State Highway Department

Figure 9-8. Hobbs average daily traffic, 1976.

The impact of future population growth is expected to be particularly heavy on streets connecting the north side of Hobbs to other parts of town. However, the only north-side locations that appear to have any serious potential for crowding are the intersections of Dal Paso and Turner with Sanger.

Peak flows are at or slightly above capacity under baseline conditions and will be marginally higher with the WIPP project. The intersection of Dal Paso with Bender will be approaching capacity in 1987 under either circumstance. The term "capacity" does not mean an absolute limit but rather that traffic movement is slowed as the capacity figure is approached. Thus, Turner and Dal Paso may experience some rush-hour problems by 1987, with the problems being slightly worse if the WIPP project is implemented. There may also be some evening rush-hour traffic problems at some downtown locations, either with or without the WIPP.

Communications services and facilities

With the implementation of the WIPP project, about 3900 additional main stations will be required by mid-1987, an increase of 32% over the 1977 level and 1% over the baseline conditions.

General Telephone of the Southwest has recently installed a new exchange and plans additional installations in 1980 and 1981. It anticipates no difficulty in meeting projected demand with or without the WIPP.

Recreation

As stated in Section 9.4.6.1, outdoor recreation is generally measured over a larger geographic area than municipal limits. In Regional Market Area 6 (RMA 6), which includes Chaves, Eddy, Lea, Lincoln, and Otero Counties, demands for camping and swimming-pool facilities may not be met by 1985. However, the lack of swimming pools as measured on an RMA-wide basis may not apply to the city of Hobbs. Hobbs has four pools, two open to the general public and two available to private members only, and it appears that the demand will not exceed the supply by the year 1985. A large State park in Hobbs (at the Hobbs Industrial Air Center), to be completed in 1983, will alleviate the current shortage of campsites within the RMA, particularly in the vicinity of Hobbs.

Peak impact on Hobbs is expected during 1983, at which time it is expected that overall recreational demands will be met.

Solid-waste management

Two additional vehicles will be needed in Hobbs in order to meet the refuse collection needs in 1987. With the WIPP project the number of new vehicles needed will be essentially the same.

By 1982, all of the present collection vehicles will be more than 7 years old. Therefore, it is projected that 11 new vehicles will have to be purchased by 1987.

With an estimated remaining life of 30 years, the landfill in Hobbs has sufficient capacity (even with the WIPP project) to meet the needs of the city until after the year 2000.

9.4.7 Government*

9.4.7.1 Scenario I: Carlsbad, Eddy County

Carlsbad

In fiscal year 1983-84, the year of maximum WIPP-construction impact on population, Carlsbad municipal revenues are projected to reach $10.9 million (in 1977 dollars) under baseline conditions (for additional information, see Appendix M, Table M-10), or about $340 on a per-capita basis. With the implementation of the WIPP project, revenues would reach nearly $11.7 million in 1983-84. The peak-year impact of the WIPP will add about $0.8 million to Carlsbad revenues (Appendix M, Table M-11).

The first year of long-run operation, 1986-87, will result in an additional $0.3 million in municipal revenues. Total revenues without the project should reach $11.6 million, while those with the project should be $11.9 million.

Carlsbad municipal expenditures are projected to be $11.3 million in 1983-84 under baseline conditions, while implementation of the WIPP should raise spending to more than $11.8 million. Implementation of the WIPP will increase municipal expenditures by $0.6 million.

By 1986-87, Carlsbad expenditures are expected to reach $12.0 million under baseline conditions and $12.2 million with the WIPP, which would thus increase fiscal 1986-87 spending by $0.2 million.

As shown by Table M-11 of Appendix M, the net fiscal impact of the WIPP project is projected to be an excess of revenues over expenditures of just over $0.2 million in 1983-84 and less than $0.1 million in 1986-87.

Eddy County

Eddy County revenues are projected to reach $4.1 million in fiscal 1983-84 under baseline conditions and $4.3 million with the implementation of the WIPP (for additional information, see Appendix M, Table M-12). In 1986-87, revenues should reach $4.3 million without the project and nearly $4.4 million with it. The peak impact of construction and operation would be to add $0.2 million to revenues in 1983-84 and less than half of that in 1986-87 (Appendix M, Table M-13).

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*For an explanation of revenue and expenditure projection techniques, see Appendix L. Revenues and expenditures are rounded, where feasible, to the nearest $0.1 million in this section. For detailed figures, see Appendix L.

Expenditures for Eddy County are projected to be $3.4 million in 1983-84 under baseline conditions. The WIPP project should raise spending to $3.5 million for the fiscal year, an increase of over $0.2 million due to the WIPP.

Under existing conditions and assumptions used in this analysis, for fiscal 1982-83, the WIPP will add $24,000 more to expenditures than to revenues in Eddy County; in 1986-87, additions to expenditures would exceed revenues by $8000.

9.4.7.2 Scenario II: Hobbs, Lea County

Hobbs

The maximum population impact of WIPP construction will occur in fiscal year 1983-84. In that year, Hobbs municipal revenues should reach $11.3 million under baseline conditions (for additional information, see Appendix M, Table M-14). The WIPP project would raise revenues to $11.5 million, an increase of $0.25 million for 1983-84 (Table M-15).

In the first year of long-run operation impact, fiscal 1986-87, revenues are projected at $12.2 million under baseline conditions and $12.3 million with the project, a difference of $0.1 million.

Hobbs municipal expenditures are projected to be $7.4 million in 1983-84 under baseline conditions and $7.6 million with the WIPP, which would raise spending by approximately $0.2 million in 1983-84. In 1986-87, municipal spending should reach $8.0 million without the project and $8.1 million with the WIPP, an increase of $0.08 million project.

The net effect of the WIPP project on the Hobbs municipal budget is projected to be a surplus of revenues over expenditures of $0.05 million in 1983-84 and $0.02 million in 1986-87.

Lea County

Lea County revenues are projected to reach $4.6 million in 1983-84 under baseline conditions and show an additional increase of $0.06 million with the WIPP (for additional information, see Appendix M, Tables M-16 and M-17). For 1986-87, baseline revenues should be $4.8 million, and the WIPP project should increase these revenues by less than $0.03 million.

Lea County expenditures for 1983-84 are projected at $3.7 million under baseline conditions and $3.5 million with the WIPP, which would raise spending by about $0.07 million for the year. In 1986-87, the WIPP is projected to raise spending by $0.03 million from the $4.0 million baseline level.

The net fiscal impact of the WIPP on Lea County is projected to be small. For 1982-83, it will raise spending by $9000 more than revenues. In 1986-87, the net deficit falls to $3000.

9.4.7.3 School District Finances

Scenario I: Carlsbad District

The principal impact of the WIPP reference repository on Carlsbad school expenditures is expected to be on operation expenses. Capital spending should not be affected because the school system is projected to have excess capacity, with or without the WIPP, for the foreseeable future. The peak impact on school spending is expected in 1983-84, when expenditures increase about $617,000 over baseline levels (Appendix M, Table M-18).

District revenues are expected to increase more than spending due to the WIPP. In the peak impact year of 1983-84, revenues are projected to be $762,000 greater with the WIPP than without, largely because of increases in district property tax revenues.

Scenario II: Hobbs District

As in Carlsbad, the WIPP is not expected to substantially affect capital spending in the Hobbs District by increased enrollments. Hobbs will require a new school in the rapidly growing northern part of the city; this school will be required with or without the WIPP. The greatest WIPP-related increase in operating expenses ($268,000) will occur in 1983-84 (Appendix M, Table M-19).

District revenues are projected to rise by more than spending as a result of the WIPP. In 1983-84, revenues will be $371,000 more with the WIPP than without it.

9.4.8 Socioeconomic Effects Under Changed Circumstances

If the basic conditions assumed in this analysis change, the predicted impacts will change. If the project is delayed, apparent costs will rise because of inflation. If economic activities in Eddy and Lea Counties are appreciably different, then the degree of migration or employment of local individuals may change significantly. In general, if the economic conditions are not as bright as forecast, the impacts of the WIPP reference repository will not be as great because more construction workers will be available from the local area. Conversely, if the economic conditions are such that there is a shortage of construction workers beyond that forecast, then a heavier degree of migration to local communities will be necessary in order to meet WIPP employment requirements.

9.5 LONG-TERM EFFECTS

During the long term, for thousands of years after the WIPP reference repository has ceased operation and has been closed up, the expected release of radioactive material is zero.

Nevertheless, natural events or intrusion by people could conceivably cause such a release. The first section of this chapter studies unexpected releases by assuming that they will occur and by assessing their consequences. The second section discusses long-term effects that do not involve any release of radioactive material; heat from the stored waste and natural subsidence of the repository could produce such effects. A final section briefly reviews the available technical information on interactions that may occur between the waste and the rock in the repository.

9.5.1 Effects Involving the Release of Radioactivity

9.5.1.1 Basis of This Analysis

The principal benefit expected from placing nuclear wastes deep underground is long-term isolation from the biosphere. Numerous studies have, however, examined the impacts that buried nuclear waste might exert on the environment if it escaped from a repository (Bradshaw and McClain, 1971; USAEC, 1971; Claiborne and Gera, 1974; McClain and Boch, 1974; Gera, 1975; Gera and Jacobs, 1972; Bartlett et al., 1976; Cohen, 1977; Cohen et al., 1977); a recent, detailed collection of references appears in a document published by the U.S. Nuclear Regulatory Commission (NRC, 1976). These analyses have pointed out that such releases of waste are highly improbable and that they would pose little hazard to the biosphere. Such results have encouraged the investigation of geologic disposal and have led to the detailed, site-specific analysis performed for the WIPP project and described in this section.

Since radioactive decay will reduce radiation levels as time passes, some studies have attempted to decide at what time after burial the waste is no longer dangerous. Different criteria for safety have led to different conclusions. Hamstra (1975), for example, compared the hazards of buried waste to those of buried uranium ore and concluded that deeply buried high-level waste is safe after about 1000 years of burial. Gera (1975) adopted a more conservative criterion. He compared the hazard of nuclear waste to the hazard of unburied uranium-mill tailings piles. Taking no account of the increased safety that burial would provide, Gera concluded that the waste decays to a safe level in 100,000 years. His study recognized, however, that this estimate could reasonably be reduced to a few thousand years under other assumptions.

The long-term integrity of the WIPP reference repository depends on multiple barriers, features that hinder the release of radioactivity. These barriers are the waste and its containers, the salt, and the geologic and hydrologic system in which the repository is embedded. The long-term safety analysis made for the WIPP indicates that the waste and its containers are not important in hindering the release of radioactivity; the important barrier is

the massive salt bed itself. About 1200 feet of rock salt lies above the waste horizons, and another 1200 feet of rock salt and anhydrite lies beneath them; no natural process is expected to disturb this 2400-foot barrier in any significant way during the period required for the wastes to decay to innocuous levels. If the salt were breached, however, the properties of the third barrier, the geologic and hydrologic system, would become important; the analysis for the WIPP has concentrated on the effectiveness of this barrier after a postulated breaching event has disturbed the other two barriers.

The basic plan for the analysis, therefore, is to estimate the consequences of hypothetical events that might move wastes to the biosphere. After postulating mechanisms for the release of radionuclides from the burial medium, the study predicts radionuclide transport through the surrounding geologic media and then through the biosphere. The amounts of radionuclides that might reach people are estimated; the estimated concentrations are used to calculate the radiation doses that might result from the hypothetical release.

9.5.1.2 Methods Used in This Analysis

Fundamental plan

This study of long-term impacts follows the basic plan of earlier studies: it evaluates the consequences of well-defined hypothetical future events that could conceivably release waste from a repository. It differs, however, from previous studies in three important aspects that make the analysis directly applicable to the WIPP reference site, the WIPP conceptual design, and the waste being considered for the project:

1. The wastes are not assumed safe after several hundred years or even a few thousand years. Consequences are evaluated as a function of time after each release event.

2. The repository is assumed to contain both contact-handled TRU waste and high-level waste in the form of spent fuel. Earlier studies have usually considered only high-level waste.

3. The analysis is specific to the reference site. It uses detailed geologic and hydrologic models of the area around the site. These models include data from field investigations conducted as part of the WIPP project.

An array of computational tools is used to examine scenarios for waste release. The term "scenario" here refers to the details describing a postulated release of radioactive material from a repository. These details specify the following:

1. A release event that breaches the repository.
2. A mechanism for moving radionuclides through the breach.
3. The elapsed time between burial and the releasing event.
4. The response of the burial medium to the breach.

The scenario, combined with a source term specifying the radionuclide inventory and the physical and chemical condition of the waste, is used to

give initial and boundary conditions for calculating the migration of radionuclides through the geologic media and to the biosphere. The movement of radionuclides to man and the dose to man are then calculated. The overall systems analysis is diagrammed in Figure 9-9.

Compilation of scenarios

The compilation of scenarios began with an extensive list of events that in concept are capable of releasing nuclear waste from a repository at the reference site. As mentioned above, numerous studies have listed and evaluated such events. In addition, a fault tree used in a German study (Proske, 1976) and a fault tree prepared by the WIPP staff aided the selection of release events. The final list comprised 19 basic release events, some produced by human activity and others produced by natural processes.

Each of the events could, in theory, give rise to several scenarios because, as explained above, a complete scenario involves many details besides a releasing event. If, for example, the waste is assumed to have degenerated into a partly liquid form at the time of release, the scenario must differ in its specifications from a scenario involving solid waste. Or if the salt medium is assumed to flow quickly enough to reseal itself after a hypothetical breach, the scenario must describe the closing of the release path. Excluding scenarios describing nuclear criticality (Section 9.5.3.6), the total number of distinct scenarios derived in the study is 94. Many are similar, differing only in minor details.

It is not possible to be certain that all potential release mechanisms have been identified. Thus, for completeness, a bounding-condition scenario, called scenario 4 in the list below, has been included: all the waters that normally flow in the Rustler aquifer above the repository are assumed to flow through the repository and then back to the Rustler.

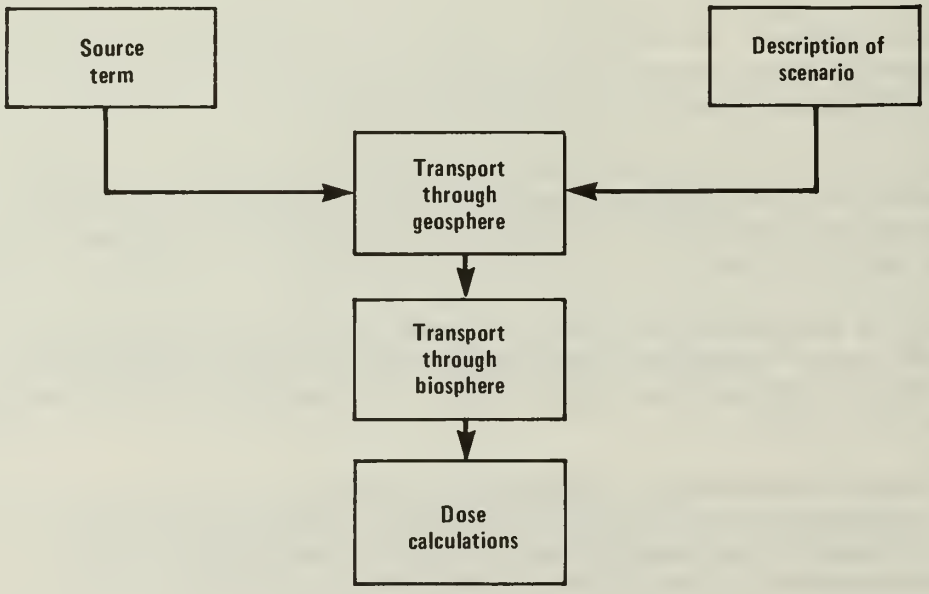

Figure 9-9. Plan of calculation.

Selection of scenarios for analysis

Examination of the 94 scenarios revealed that 90 of them result in the introduction of radionuclides into the Magenta and Culebra aquifers of the Rustler Formation above the repository. The remaining four scenarios result in the direct transfer of radionuclides to the surface.

Five representative scenarios were chosen for the analysis. Scenarios 1 through 4 introduce the radionuclides into the Magenta and Culebra aquifers. These radionuclides are subsequently transported in the aquifers to the outlet along the Pecos River near Malaga Bend, approximately 15 miles southwest of the site. At this point the radionuclides reach the biosphere. Scenario 5 introduces the radionuclides directly into the biosphere through a drill shaft penetrating the repository. All five scenarios are summarized below.

Scenario 1: A hydraulic communication connects the Rustler aquifers above the repository, the Bell Canyon aquifer of the Delaware Mountain Group below the repository, and the repository.

Scenario 2: A hydraulic communication allows water to flow from the Rustler, through the repository, and back to the Rustler.

Scenario 3: A stagnant pool connects the Rustler aquifers with the repository. In contrast to scenarios 2 and 3, which involve flowing water, this communication permits radionuclide migration to the Rustler only by convection or molecular diffusion.

Scenario 4: A hydraulic communication connects the Rustler aquifers with the repository; all the Rustler water normally moving above the repository flows through the repository and back to the Rustler. In contrast, scenarios 1 and 2 establish only a limited hydraulic connection.

Scenario 5: A drill shaft penetrates the repository and intercepts a nuclear-waste canister; the radioactive material is brought directly to the surface.

Scenarios 1 through 3 might be consequences of human actions or of natural geologic events. They might, in principle, begin to form during repository construction and operation or much later, as a result of interactions between the buried waste and the salt. Scenario 4 would be the consequence of a major geologic event, while scenario 5 would be the result of human actions.

9.5.1.3 Scenarios for Liquid Breach and Transport

Scenarios 1 through 4 are referred to as scenarios for liquid breach and transport. As explained in the remainder of this section, the analysis of their consequences proceeds from a detailed description of each scenario to a calculation of radionuclide movement through the geosphere--movement from the repository and through the Rustler aquifers. Next the analysis predicts radionuclide transport through the biosphere after discharge into the Pecos River at Malaga Bend. The final calculations predict radiation doses received by people.

Description of scenarios

The first step in the analysis outlined in Figure 9-9 is the block that represents the description of a scenario. Four major specifications make up this description.

Breaching event. For computer modeling, the specification of an event that breaches the repository consists of parameters for input to the geosphere-transport model shown as another block in Figure 9-9. These parameters describe the rate at which radionuclides leave the repository and enter the geosphere. No general prescription for specifying this input applies to all four scenarios because each requires its own modeling techniques.

Transport mechanism. In all four scenarios, the transport mechanism is water flow. Details of the flow differ among the scenarios; the specific modeling techniques used for each of them are described later in this section, in the discussion of scenario modeling.

Time of breach. The study models breaches of the repository and release to the aquifer at 100 and 1000 years after burial. Events at more-distant times are adequately represented by the 1000-year modeling because later changes in waste form and nuclide inventory are so slow as to give rise to no perceptibly different effects.

Response of burial medium to releasing event. This specification, like that of the breaching event, consists of rates and durations of release used in the geosphere-transport code. The specific methods used for each scenario are described in the discussion of scenario modeling.

Source term

The second step in the analysis is to compile the source term shown as a block in Figure 9-9. Two major specifications compose the source term.

Radionuclide inventories. The amount of each radionuclide present during the release depends on the type of waste held in the repository and on the time at which release occurs. Because actual radionuclide inventories will vary among the containers received at the repository, it is necessary to specify typical values. For this purpose the study used actual assay data from the Idaho National Engineering Laboratory for contact-handled TRU waste and computations by Sutherland and Bennett (in press) for spent fuel (Appendix E). A spent-fuel canister was assumed to contain one PWR spent-fuel assembly. To calculate radionuclide inventories at each time selected for modeling, a computer code (Appendix K) used the known decay characteristics (half-lives and daughter nuclei) of each radionuclide in the assays. Tables 9-43 and 9-44 list the calculated radionuclide inventories at the repository-breach times in this study. The tables list the radionuclides that are the most important in long-term consequence assessments. Although the inventory listed in these tables is not precisely the same as that shown in Appendix E, the differences are such that the release consequences are not affected.

The radionuclides included in these inventories produce nearly all the radioactivity present in the waste. At 1000 years, the total mass of

Table 9-43. Nuclide Concentrations at Repository Breaching (CH TRU Waste)

Nuclide	Half-life (yr)	Concentration at 100 yr		Concentration at 1000 yr	
		Ci/liter	g/liter	Ci/liter	g/liter
Ra-226	1.6 + 3[a]	3.3 - 7	3.3 - 13	1.1 - 4	1.1 - 10
Th-229	7.3 + 3	6.6 - 9	3.2 - 14	7.2 - 6	3.4 - 11
Th-230	7.7 + 4	2.2 - 5	1.2 - 9	6.3 - 4	3.3 - 8
Th-232	1.4 + 10	4.6 - 12	4.6 - 11	4.5 - 10	4.5 - 9
U-233	1.6 + 5	2.4 - 6	2.6 - 10	2.2 - 4	2.4 - 8
U-234	2.4 + 5	4.6 - 2	7.4 - 6	8.5 - 2	1.4 - 5
U-235	7.0 + 8	2.7 - 4	1.3 - 4	2.7 - 3	1.3 - 3
U-236	2.3 + 7	1.9 - 3	3.1 - 5	1.8 - 2	2.9 - 4
Np-237	2.1 + 6	1.3 - 2	1.9 - 5	8.7 - 2	1.3 - 4
Pu-238	8.8 + 1	1.1 + 2	6.5 - 6	1.0 - 1	6.1 - 9
Pu-239	2.4 + 4	2.8 + 3	4.6 - 2	2.7 + 3	4.5 - 2
Pu-240	6.5 + 3	6.7 + 2	3.1 - 3	6.1 + 2	2.8 - 3
Am-241	4.6 + 2	4.7 + 2	1.4 - 4	1.2 + 2	3.8 - 5

[a]1.6 + 3 = 1.6×10^3.

actinides in spent fuel is 4.40×10^5 grams per canister; virtually all of this mass is included in the geosphere-transport calculations. The total mass of fission products is 1.55×10^4 grams, of which 610 grams (technetium-99, iodine-129, cesium-135) are modeled. The modeling includes 96.6% of the weight of the waste, 98.6% of the radioactivity in the waste, and all the isotopes of critical concern.

Physical and chemical condition of the waste. Because waste-acceptance criteria for contact-handled TRU waste will not be established until the summer of 1979, the source term cannot include an accurate description of the physical and chemical forms of the waste. Consequently, this analysis assumes conditions that produce upper bounds on the amounts of waste released. To this end the detailed model assumes that when water comes into contact with waste the radionuclides dissolve with the salt. It also assumes that the radionuclides are easily transported by water. In future analyses, these assumptions may be replaced if experimental data show that such phenomena as leaching, waste-matrix degradation, and the valence states of the radioactive species significantly affect the release rates.

Geosphere-transport calculations

The numerical model used in the geosphere-transport calculations (a block in Figure 9-9) is based on a model developed for the U.S. Geological Survey (Intercomp, 1976). The model was later modified for the U.S. Nuclear Regulatory Commission to describe the migration of radionuclides. This modification (Dillon, Lantz, and Pahwa, 1977) was used in the present study. A detailed mathematical discussion of the model and its application to this analysis appears in Appendix K.

Briefly, the model solves three coupled partial-differential equations describing the behavior of a liquid injected into an aquifer system. The three equations describe conservation of energy, total liquid mass, and mass

Table 9-44. Nuclide Concentrations in Spent-Fuel Assemblies at Breaching Times of 100 and 1000 Years

Nuclide	Half-life (yr)	Concentration g/liter	Concentration Ci/liter
	Time = 100 years[a]		
Sr-90	28.1	1.2-1[b]	10.5
Cs-137	30.1	4.8-2	6.8
	Time = 1000 years		
Tc-99	2.1+5	8.0-1	1.4-2
I-129	1.6+7	2.8-1	3.1-5
Cs-135	2.3+6	2.8-1	3.2-4
Ra-226	1.6+3	2.6-6	2.6-6
Th-229	7.2+3	5.6-7	1.2-7
Th-230	7.7+4	8.0-4	1.4-5
Th-232	1.4+10	1.3-4	1.4-11
U-233	1.6+5	3.1-4	3.0-6
U-234	2.4+5	2.9-1	1.8-3
U-235	7.0+8	7.5	1.6-5
U-236	2.3+7	4.5	2.9-4
U-238	4.8+9	8.8-2	3.0-4
Np-237	2.1+6	1.3	9.1-4
Pu-239	2.4+4	5.0	3.0-1
Pu-240	6.5+3	1.9	4.2-1
Pu-242	3.9+5	3.5-1	1.4-3
Pu-244	8.3+7	4.3-10	7.6-15
Am-243	7.4+3	9.0-2	1.7-2

[a]These nuclides are added to those listed below under the 1000-year breaching time.

[b]1.2-1 = 1.2×10^{-1}.

of specific contaminants dissolved in the injected fluid. An additional equation for each radioactive species accounts for conservation of mass of the species when dissolved in the fluid phase and when adsorbed onto the rock medium; it also accounts for radioactive decay and generation. Solutions are calculated for finite-difference equations on a three-dimensional rectangular grid, with the following assumptions:

1. Transient, laminar flow takes place in three dimensions.

2. Fluid density can be a function of pressure, temperature, and concentration of the inert component, while fluid velocity can be a function of temperature and component concentration.

3. The injected waste liquid is miscible with in-place aquifer liquid.

4. Aquifer properties vary with position; porosity, permeability, thickness, and elevation can be specified for each grid block of the model.

5. Hydrodynamic dispersion is a function of fluid velocity.

6. Radioactive species are present in trace quantities and do not alter the physical properties of the fluids involved.

7. The energy equation can be described as

   (enthalpy in) - (enthalpy out) = (change in internal energy of the system).

8. Boundary conditions allow natural water movement in the aquifer, heat loss to adjacent formations, and the location of injection, production, and observation points anywhere in the system.

The following steps outline the approach used in calculating geosphere transport:

1. Regional modeling: A computer code modeled the Delaware basin hydrology in a square area 36 miles on a side. Local boundary conditions were determined for this model. Then calculations performed with the model defined aquifer communication (or lack of it) and aquifer flow rates; they also tested the consistency between model-generated numbers and hydrologic measurements in the field.

2. Scenario modeling: For each scenario calculations of water flow are performed in both two and three dimensions.

3. Transport through aquifers: Because the dimensions of the aquifer are small in comparison with the geologic cross section of the basin, calculations in one and two dimensions are adequate for the movement of nuclides from the repository, through aquifers, and to the point where discharge to the biosphere is assumed to occur.

An important part of modeling the scenarios for liquid breach and transport is the assumption of two separate values for the transmissivity of the combined Culebra and Magenta aquifers, which the code models as a single 40-foot-thick aquifer called simply the Rustler aquifer in the remainder of this chapter. The analysis uses these two values to establish upper and lower bounds to its predictions of flow rates because the values measured in the field may not be applicable over the entire repository.

Biosphere-transport calculations

Having moved from the repository through the Culebra and Magenta aquifers, the radionuclides could reach the Pecos River near Malaga Bend. At that point the radionuclides, diluted when the aquifer water mixes with the river water, would enter the biosphere. Possible pathways by which they might move through the biosphere to people include the ingestion of fish, the ingestion of water, and activities like swimming, boating, and sunbathing.

The biosphere-transport calculations (a block in Figure 9-9) begin by converting the output of the geosphere-transport code, which provides mass fractions of radionuclide concentrations in the aquifer water. For each

radionuclide, the mass fraction is converted to picocuries per year by the following equation:

(mass fraction)(aquifer flow rate)(specific activity) = (activity per year)

where the dimensions of the factors are

$$[(g/ml)/(g/ml)]\ (lb/yr)(pCi/g)(g/lb) = (pCi/yr).$$

Then the analysis calculates the yearly intake of radionuclides by a person exposed through the biosphere pathways.

Dose calculations

The consequence analysis next computes the radiation doses that result from the intake of radionuclides by a hypothetical person living near Malaga Bend. This calculation (Torres and Balestri, 1978), represented by the bottom block in Figure 9-9, uses the NRC computer code LADTAP.

When radioactive material is taken into the body, part of it remains there, delivering a radiation dose until it decays or is eliminated by biological processes. To express the dose received from such material, the annual dose delivered while the material is in the body is integrated over a 50-year period after injection. The integrated dose from a 1-year intake of radioactive material is called the 50-year dose commitment.

In this calculation the yearly intake from ingesting water or fish is converted to a 50-year dose commitment by the following equation:

(yearly intake) (liquid-dose conversion factor) = dose commitment

where the dimensions of the factors are

$$(pCi/yr)\ [mrem/(pCi/yr)]\ (10^{-3}\ rem/mrem) = rem.$$

The conversion factors for this equation are taken from the NRC study NUREG-0172 (Hoenes and Soldat, 1977). When a person continually ingests radioactive material (as the hypothetical person in this study does), the 50-year dose commitment, expressed in rem, is numerically equal to the annual dose, expressed in rem per year, received by the body during the 50th year after ingestion. For this reason, the calculated dose-commitments presented later in this chapter are expressed as dose rates, in rem per year.

To account for swimming, boating, and use of the river shoreline, the study uses the methods given in NRC Regulatory Guide 1.109, Revision 1 (NRC, 1977). It also uses the factors provided by this Guide for computing

exposures and doses to individuals characterized by the Guide as "maximum" with respect to food consumption, occupancy, and other pathways. Further information on the biosphere-transport calculations appears in Section 9.5.1.4.

Scenario modeling

Although the detailed descriptions in the following pages refer specifically to scenarios 1, 2, 3, and 4, the modeling is general enough to represent many scenarios.

Modeling of scenario 1. This scenario develops a vertical connection between the upper aquifer (the Rustler) and the lower aquifer (the Bell Canyon) through a hypothetical 9-inch-diameter uncased borehole (Figure 9-10). Depending on the actual location of this borehole, flow may be either into or from the upper aquifer. Recent measurements (Powers et al., 1978) and the calculated freshwater potentials suggest that for the purpose of analysis, the flow near the repository can be assumed to be upward, into the Rustler aquifer, under a pressure difference of 7.5 psia. The calculations therefore assume this upward flow.

The permeability of the wellbore was calculated using Hagen-Poiseuille's law for laminar flow through a pipe. The hydraulic resistance of the wellbore was found to be negligible relative to the resistances of the aquifers.

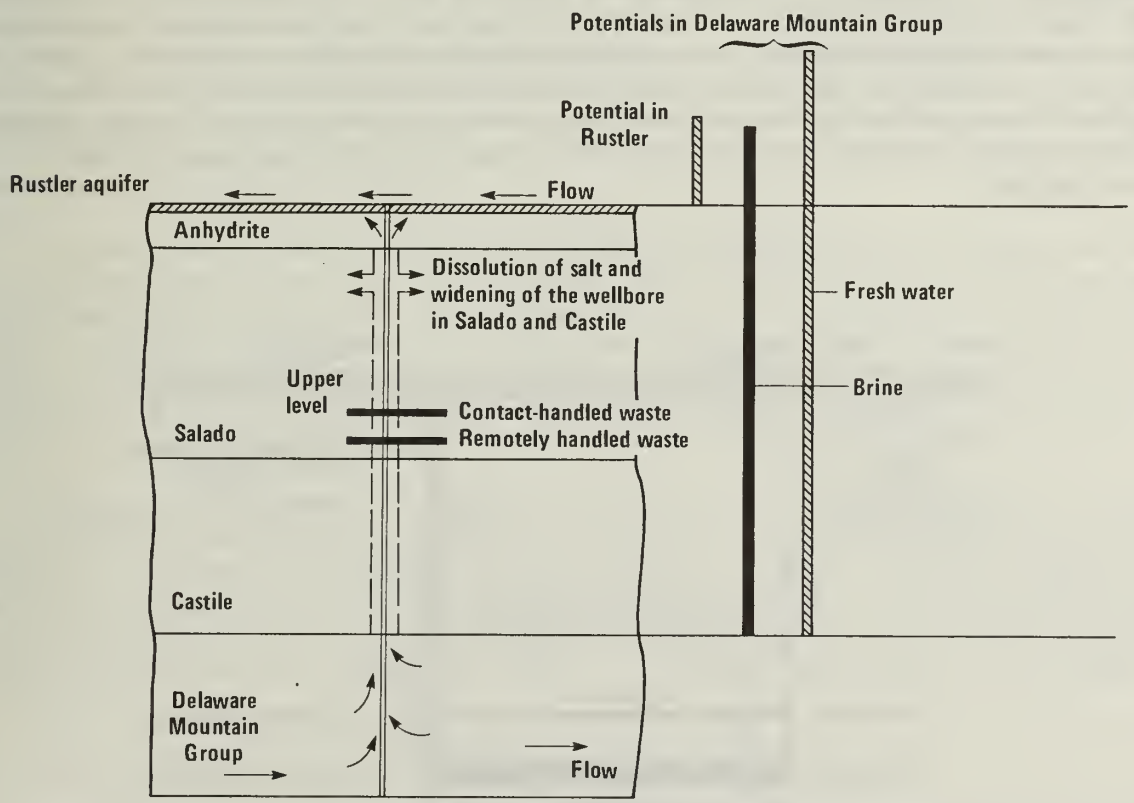

Figure 9-10. Schematic representation of scenario 1.

Calculation of the flow through the wellbore was performed by simulating the hydraulic conditions of the two aquifers connected by a borehole. In this scenario, water is withdrawn from one aquifer and injected into the other. Since the transmissivity of the upper aquifer is less than that of the lower aquifer, the upper-aquifer transmissivity controls the flow rate through the wellbore. A somewhat conservative and simple way of modeling this situation is to describe the upper aquifer numerically as a single layer with an infinite radius and the wellbore at its center. The boundary condition at the wellbore is schematically shown in Figure 9-10.

In this model, after an initial transient period, the flow becomes essentially constant. The calculations predicted flow rates for times as long as 100,000 years. From the two bounding values of the transmissivity in the Rustler aquifer, upper and lower bounds to flow rates through the wellbore were calculated to be 600 and 30 ft^3/day. The predictions of the consequence analysis were calculated separately for each of the two bounds on transmissivity.

It was assumed that the Salado and Castile Formations dissolve uniformly along the length of the wellbore and that the radioactive-waste canisters dissolve at the same rate as the salt formation. The diameter of the hydraulic communication increases as the water dissolves the salt; a dissolution front advances through the repository, eventually reaching all the stored waste. The amount of waste dissolved is proportional to the fraction of the geologic formations that is waste.

Modeling of scenario 2. Scenario 2 (Figure 9-11) consists of the failure of two shafts near the center of the repository and the development of a hydraulic communication through an abandoned 24-inch-diameter wellbore. The wellbore is assumed to be located at the downstream end (toward the Pecos River) of the repository. Conceivably water can flow from the Rustler aquifer down the shafts, through the two repository levels, and then back to the Rustler aquifer.

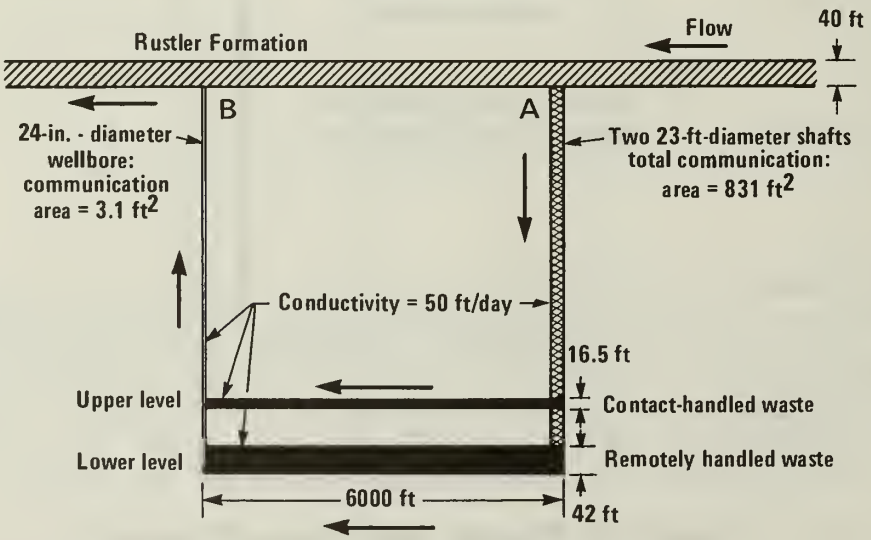

Figure 9-11. Schematic representation of scenario 2.

For modeling purposes it is assumed that the water entering the repository contains 8000 ppm of total dissolved solids, the concentration of the Culebra and Magenta waters, and that the water coming out is saturated brine with a total-dissolved-solids concentration of 410,000 ppm. Furthermore, both repository levels are assumed to dissolve at the same rate, with the dissolution of radioactive waste controlled by the dissolution of salt. In other words, the leach rate of waste is assumed to equal the leach rate of salt.

The permeability of the two 23-foot-diameter* shafts and the repository levels is taken as 50 times the permeability of the Rustler aquifer. This number, typical of a highly permeable aquifer, is believed to be conservative because salt creep would tend to fill voids left in the repository after backfilling or to heal fractures or failures developed in the shafts or the wellbore. Even though the spent-fuel repository will not extend 6000 feet from the shaft, a conductivity of 50 ft/day is assumed between the shaft and the wellbore at the repository level. Since relatively fresh water goes down the shafts and saturated brine (of higher fluid density) comes up the wellbore, the actual potential gradient across the shafts, the repository, and the wellbore would be lower than assumed. Therefore, not allowing for fluid-density change due to salt dissolution is a conservative assumption.

Flow calculations for this scenario were made by a three-dimensional two-layer description of the system. The upper layer was the Rustler, and the lower layer represented the two repository levels. Between points A and B in Figure 9-11 are two parallel resistances to flow--the Rustler aquifer and the repository levels. A significant amount of water flows through the repository because it is assumed to have a lower resistance to flow; nearly all the resistance in the repository communication is the hydraulic resistance of the wellbore because of its much smaller flow area. The permeabilities of the shaft area and the repository therefore do not control the flow through this communication, as long as the resistances of these two members are small. The waste-dissolution rate for scenario 2 was calculated to be less than that for scenario 1 by a factor of 2.17.

In scenario 1, some fluid from the Bell Canyon aquifer is added to the Rustler aquifer; after this addition the fluid velocity in the Rustler aquifer increases slightly--roughly by a factor of 1/6. In scenario 2, no fluid is added; the velocity between the repository and the river is essentially the natural velocity in the Rustler aquifer. Therefore, if consequences for scenario 2 are obtained from scenario 1 by using the ratio of 2.17, the results are slightly conservative but adequate predictions for scenario 2.

Modeling of scenario 3. Simple circumstances producing scenario 3 might include one or more drill holes penetrating the Rustler and reaching the repository. Although such holes would eventually fill with water, there would be no driving mechanism to make it flow. The transport of radionuclides would therefore be much slower than transport in scenarios 1 and 2. A series of deep cracks above the repository might, in theory, also give rise to this scenario.

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*The diameter of the largest shaft at the reference repository has been changed to 19 feet (Section 8.4.1) since this calculation was made. However, the results are not sensitive to the change.

In more technical terms, this scenario assumes that a vertical connection is developed between the repository and the Rustler aquifer. However, lack of horizontal communication prevents water flow within the repository (Figure 9-12). The only mechanism assumed for waste transport from the repository to the aquifer is molecular diffusion in the liquid phase. Liquid-liquid diffusivities are on the order of 10^{-3} ft^2/day (10^{-5} cm^2/sec) (Perry, 1963); this value was used in the analysis.

As in scenarios 1 and 2, salt dissolution is assumed to determine the leach rates of the waste. Saturated brine is assumed to exist in the repository, and water containing 8000 ppm of total dissolved solids is assumed in the Rustler aquifer, establishing a constant gradient for diffusion. Since diffusivity is constant under these conditions, the area of communication is the controlling parameter for salt and waste transport into the aquifer. To derive worst-case concentrations for this study, this area is taken as 35 acres, far larger than the area that drill holes might credibly produce. Flow conditions in the Rustler aquifer are assumed to be independent of the events in this scenario.

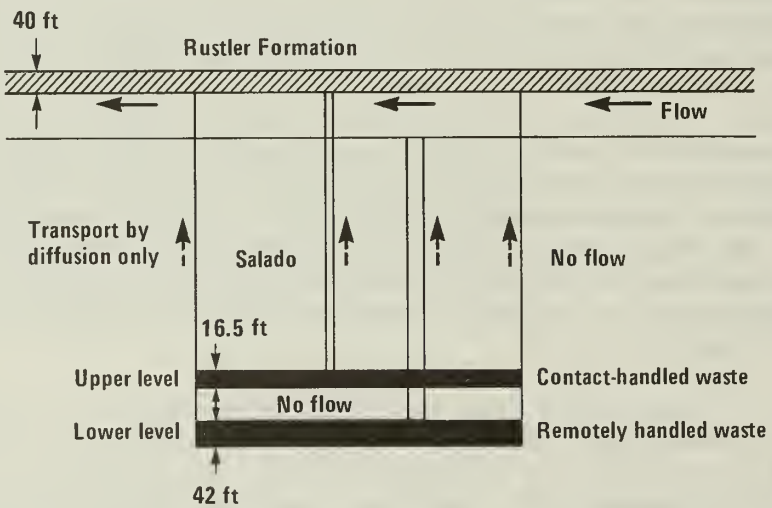

Figure 9-12. Schematic representation of scenario 3.

Modeling of scenario 4. The three scenarios described above depict repository failures that, although unlikely, are physically possible. The worst-case failure is also of interest as a bounding condition since it spawns the most severe consequences of the scenarios for liquid breach and transport; it is even more unlikely than the other three scenarios.

In the bounding-condition scenario, the total flow in the Rustler Formation over the entire width of the repository passes through the two repository levels and back to the Rustler (Figure 9-13). Water entering the repository is assumed to contain 8000 ppm of total dissolved solids, the concentration of the Culebra and Magenta waters; water coming out is saturated brine with a total-dissolved-solids concentration of 410,000 ppm. Furthermore, both repository levels are assumed to dissolve at the same rate, with the dissolution

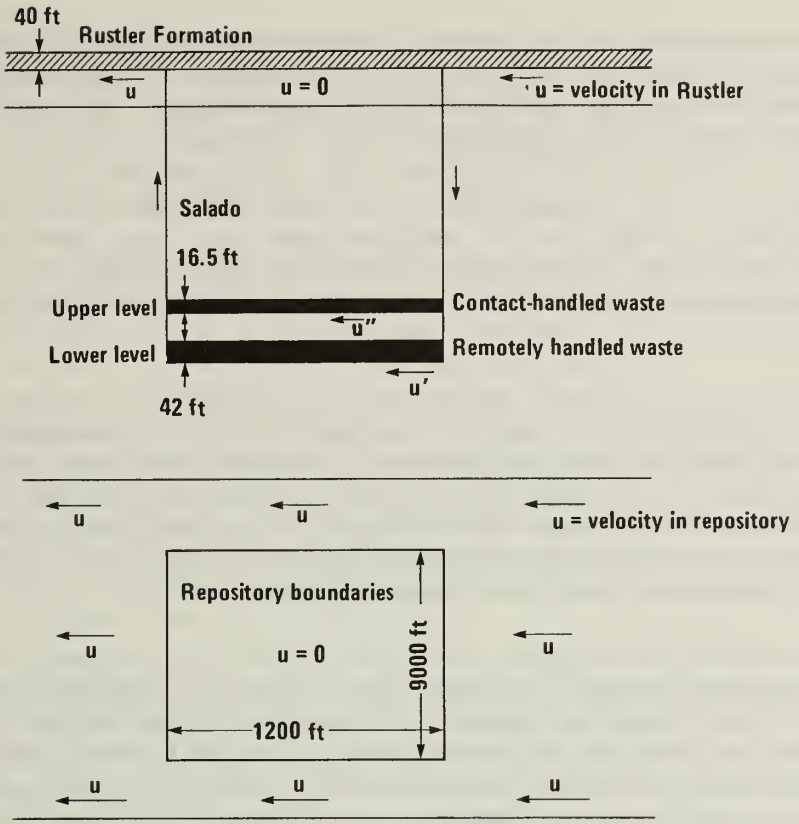

Figure 9-13. Schematic representation of the bounding condition (top) and velocities in the Rustler during the bounding condition (bottom).

of radioactive waste controlled by the dissolution of the salt. In other words, the leach rate of waste is assumed to equal the leach rate of salt.

The thicknesses of the two repository levels are taken as 16.5 and 42 feet, the total thicknesses to be mined. Except in the area above the repository, flow conditions in the Rustler are assumed to be the same before and after the scenario begins. As in scenario 1, the transmissivity of the Rustler aquifer is an important quantity; calculations for the bounding condition therefore assume the two limiting values for transmissivities.

Rates of dissolution

This section describes the rates of salt and waste dissolution calculated for each of the scenarios. All the scenarios assume that fluid entering the Rustler aquifer is saturated brine.

In scenario 1, water enters the wellbore from the Bell Canyon aquifer at 230,000 ppm (23%), dissolves salt and waste uniformly along 2700 feet of the Salado and Castile Formations, and enters the Rustler aquifer at 410,000 ppm (41%). For a formation specific gravity of 2, a formation volume equal to 9% of the fluid volume passing through the wellbore is dissolved; because fluid flow for the upper value of transmissivity was calculated to be 600 ft^3/day, 54 cubic feet of the formation is dissolved per day. Over the 16.5-foot

thickness of the CH-waste repository, the amount of the repository dissolved is (16.5/2700) x 54 = 0.33 ft^3/day (3411 liters/yr). The rate for the lower bound on transmissivity is smaller by a factor of 20. The leach rate in the RH-waste repository is proportional to its thickness, 42 feet.

In scenario 2, the steady-state flow rates through the repository were calculated to be 3.2 and 0.16 ft^3/day for the upper and lower transmissivities, respectively. At these flow rates, the salt formations, including the repository, dissolve at 0.64 and 0.032 ft^3/day (6616 and 331 liters/yr), respectively.

In scenario 3, a constant concentration gradient is assumed to exist between the repository levels and the Rustler aquifer. Assuming a concentration gradient of 400,000 ppm over an average 1500-foot distance, a diffusivity of 10^{-3} ft^2/day, and a cross-sectional area of 35 acres, the calculations predict a salt-diffusion rate of 0.2033 ft^3/day. This rate corresponds to 0.0573 ft^3/day (593 liters/yr) from the CH-waste repository and 0.0117 ft^3/day (121 liters/yr) from the RH-waste level.

In scenario 4 (the bounding condition), the total-dissolved-solids concentration increases by roughly 400,000 ppm. This corresponds to the dissolution of a volume of the formation equal to 20% of the fluid volume passing through the two repository levels. Fluid velocity through the Rustler aquifer for the upper-transmissivity bound is roughly 0.04 ft/day. For an aquifer thickness of 40 feet and a porosity of 0.1, this corresponds to a flow rate of 0.16 ft^3/day per unit width of the aquifer. When this quantity flows through the two repository levels, 0.045 ft^3/day-ft flows through the CH-waste level and 0.115 ft^3/day-ft flows through the RH-waste level. At the CH-waste level, for example, the equivalent dissolution rate is 0.009 ft^3/day per unit width, or 81 ft^3/day (8.4×10^5 liters/yr) for the complete CH-waste repository.

Nuclide transport

Geosphere-transport calculations are confined to the Rustler Formation with the discharge point at Malaga Bend on the Pecos River. The potential contours in the Rustler (Figure K-6 in Appendix K) show that flow between the repository and Malaga Bend is essentially one-dimensional (toward the Pecos River) and that all water from the Rustler discharges into the river. Therefore, dispersion calculations in the cross-flow direction do not provide any additional information; the entire plume of water carrying radionuclides would discharge into the river.

The concentration of radionuclides in the aquifer is also determined at a location 3 miles from the center of the repository (i.e., at the boundary of the site) at the centerline of the radionuclide plume. A simple procedure obtains plume-centerline concentrations from one-dimensional model calculations. One set of two-dimensional model calculations was made; from it were obtained relationships that convert one-dimensional values to plume-centerline values. These relationships can translate all other one-dimensional results into approximate two-dimensional terms.

Steady-state potentials from scenario modeling are used to represent the boundary conditions for nuclide transport. Calculations are performed up to 100,000 years after the start of each scenario.

From the dissolution rates discussed above, it is apparent that the worst consequences come from the higher-transmissivity assumption for the bounding case. Travel times for nonadsorbing radionuclides without dispersion are the same as the travel time for water. Nonadsorbing radionuclides would begin to reach Malaga Bend in approximately 5000 and 100,000 years for the upper and lower transmissivities, respectively.

Isotopes with relatively short half-lives are not explicitly included in the geosphere-transport model, because they are in secular equilibrium with their parent nuclides. In other words, the radioactivity of these isotopes is approximately the same as that of the parent nuclides.

Partial results of scenario 2 appear in Table 9-45, which presents, for all spent-fuel radionuclides, modeled transport rates integrated in the cross-flow direction at Malaga Bend and at the 3-mile location. Table 9-45 shows that highly adsorptive plutonium isotopes remain near the repository; even after 100,000 years their transport from the repository remains negligible. However, the uranium daughters of plutonium, with low adsorption coefficients, are transported farther from the repository.

Although the adsorption coefficient of thorium is greater than that of plutonium, thorium transport rates are relatively large at a considerable distance from the repository because of the generation of thorium daughter isotopes from faster-moving uranium isotopes. Therefore, in spite of its greater adsorption coefficient, thorium reaches downgradient locations faster than plutonium does.

For comparison, the transport rates of three spent-fuel isotopes (iodine-129, nonadsorbing; uranium-235, slightly adsorbing; and radium-226, moderately adsorbing) are presented in Table 9-46 for three scenarios at the assumed 3-mile point. The transport rates for scenario 1 are consistently greater than those for scenarios 2 and 3.

Arrival times and discharge rates of iodine-129 are graphed in Figure 9-14 for scenarios 1 and 4. The bounding condition (Figure 9-14b) shows the effect of rapid repository dissolution under extreme conditions; under the upper-transmissivity assumption, the entire spent-fuel repository is dissolved in

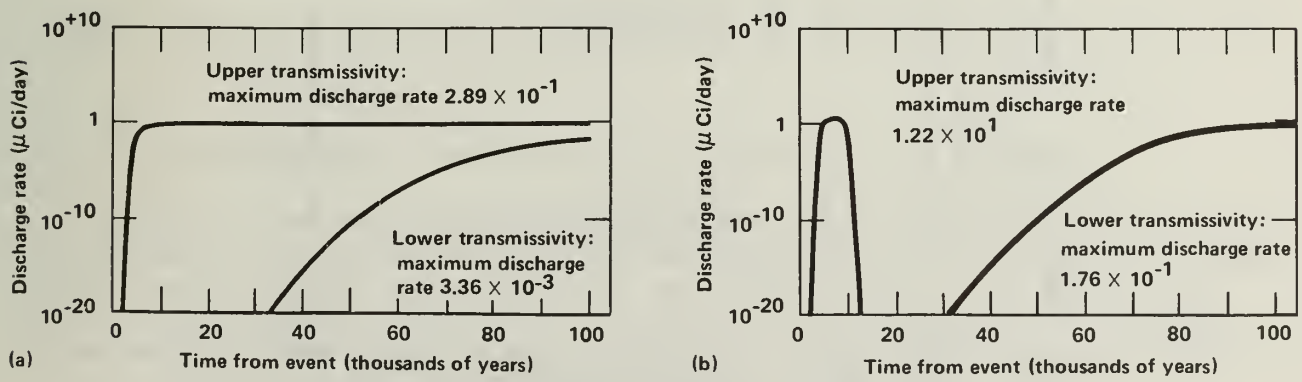

Figure 9-14. Calculated rate of I-129 discharge into the Pecos River at Malaga Bend: (a) scenario 1, (b) bounding calculation (scenario 4); event initiation, 1000 years; source of radioactivity, spent fuel.

Table 9-45. Transport Rates for Isotopes from Spent Fuel: Scenario 2, Upper Transmissivity[a]

Nuclide	3 miles		Malaga Bend		3 miles		Malaga Bend	
	g/yr	Ci/yr	g/yr	Ci/yr	g/yr	Ci/yr	g/yr	Ci/yr
	Time = 3500 years				Time = 7000 years			
Tc-99	1.1+2[b]	1.9	8.4-3	1.4-4	5.4-14	9.1-16	1.1+2	1.9
I-129	2.6+1	4.5-3	1.9-3	3.3-7	3.1-13	5.4-17	2.6+1	4.6-3
	Time = 50,000 years				Time = 100,000 years			
Cs-135	9.8-9	1.1-11	0	0	3.7-4	4.2-7	0	0
Ra-226	2.0-14	2.0-14	1.5-23	1.5-23	1.3-14	1.3-14	9.8-15	9.8-15
Th-229	3.4-17	7.3-18	1.7-26	3.7-27	3.6-17	7.6-18	9.0-18	1.9-18
Th-230	1.4-4	2.8-6	3.2-13	6.4-15	8.8-5	1.8-6	8.2-5	1.7-6
Th-232	2.3-5	4.7-12	6.6-14	7.3-21	4.3-5	4.8-12	2.2-5	2.4-12
U-233	1.6-12	1.2-15	1.8-20	1.3-23	1.6-12	1.1-15	7.9-13	5.6-16
U-234	1.1-6	6.7-9	1.9-7	1.2-9	7.3-7	4.6-9	4.5	2.8-2
U-235	2.9+1	6.2-5	6.1-6	1.3-11	6.93	1.5-5	1.8+2	3.9-4
U-236	4.1	2.6-4	3.9-6	2.5-10	2.1-2	1.4-6	1.2+2	7.6-3
U-238	2.8-1	9.5-8	6.9-4	2.3-10	2.5-1	8.7-8	1.7+4	5.7-3
Np-237	0	0	0	0	7.3-36	5.2-39	0	0
Pu-239	0	0	0	0	0	0	0	0
Pu-240	0	0	0	0	0	0	0	0
Pu-242	0	0	0	0	0	0	0	0
Am-243	0	0	0	0	0	0	0	0

[a]At Malaga Bend, the transport rate is the same as the discharge rate into the Pecos River.
[b]1.1+2 = 1.1×10^{-2}.

Table 9-46. Comparison of Transport Rates for Three Selected Isotopes (Distance = 3 Miles)

Nuclide	Scenario 1		Scenario 2		Scenario 3	
	Upper transmissivity	Lower transmissivity	Upper transmissivity	Lower transmissivity	Upper transmissivity	Lower transmissivity
			Time = 3500 years			
I-129, g/yr	7.2-1[a]	1.1-10	3.3-1	5.1-11	1.0-2	1.0-2
I-129, Ci/yr	1.3-4	2.1-14	5.8-5	3.5-15	1.7-6	1.7-6
			Time 50,000 years			
Ra-226, g/yr	6.4-6	1.7-21	2.9-7	7.9-22	8.9-8	1.4-20
Ra-226, Ci/yr	6.4-6	1.7-21	2.9-7	7.9-22	8.9-8	1.4-20
U-235, g/yr	4.9+1	2.1-12	2.2+1	3.6-13	6.8-1	3.5-12
U-235, Ci/yr	1.1-4	4.5-18	4.8-5	2.1-19	1.5-6	7.6-18

[a] $7.2\text{-}1 = 7.2 \times 10^{-1}$.

10,000 years. Because the entire inventory of iodine-129 is in the spent fuel, the upper-transmissivity bounding condition gives an iodine-129 discharge of short duration.

Uncertainty on hydraulic conductivity induces uncertainty in predicted transport rates. A preliminary analysis (Tang and Pinder, 1976) shows that

1. Changes in groundwater velocity, within the range used here, generate relatively little change in the mass concentrations at long times.

2. Increases in groundwater velocity together with increases in dispersivity cause earlier arrivals at points where concentrations are being determined. Therefore, calculations that take dispersion into account may predict earlier arrival times than those reported here, although the differences would not be great.

3. To a high degree of confidence, in each scenario the actual geosphere transport must lie within the results predicted by calculations with the two transmissivities.

4. The use of the higher transmissivity value gives conservative results.

9.5.1.4 Consequences of Scenarios for Liquid Breach and Transport

Throughout the calculations the radionuclides are assumed to originate in spent fuel and in contact-handled TRU waste; the events that breach the repository begin 100 and 1000 years after the repository has been sealed. The exposure pathways for man include the ingestion of fish and water, boating, swimming, and shoreline activities. The interfacing of the computer codes used in the assessment is described by Torres and Balestri (1978).

In addition to dose assessments, this section presents the concentration histories of radionuclides discharged at Malaga Bend and also at the center

of an underground contamination plume at a point 3 miles from the repository. The consequences of scenarios 1, 2, and 3 are discussed separately from those of scenario 4 because scenario 4 is the bounding condition.

Scenarios 1, 2, and 3

In the analysis of scenarios 1, 2, and 3, scenario 1 resulted in the most severe consequences. Repository dissolution in scenarios 2 and 3 would proceed, respectively, at less than one-half and one-fifth of the rate for scenario 1; the consequences of scenario 1 are therefore upper limits to the consequences of the other nonbounding scenarios.

Release of spent fuel: consequences at Malaga Bend. Figure 9-15 shows the time dependence of radionuclide concentrations in the Pecos River at Malaga Bend. These radionuclides originate primarily in spent fuel and begin to move toward the river when a repository breach occurs, 1000 years after waste emplacement. The calculations assume that the minimum annual flow rate of the Pecos River remains the same as now, 515 liters/sec (Claiborne and Gera, 1974). The figure presents data derived from both the upper and the lower bounds on transmissivity.

Figure 9-16 presents the annual whole-body and organ doses received by the maximally exposed person. The highest calculated whole-body dose is 3.0×10^{-5} rem/yr; the highest calculated organ dose is 2.1×10^{-4} rem/yr, to the bone. Both doses came from scenario 1 with the upper-transmissivity assumption. These doses can be compared with the whole-body dose from natural background radiation at the reference site, which is approximately 0.1 rem/yr (Section H.6 of Appendix H). If the sealed repository were to be breached, the dose received by the maximally exposed person would be less than 0.3% of the dose from natural background radiation.

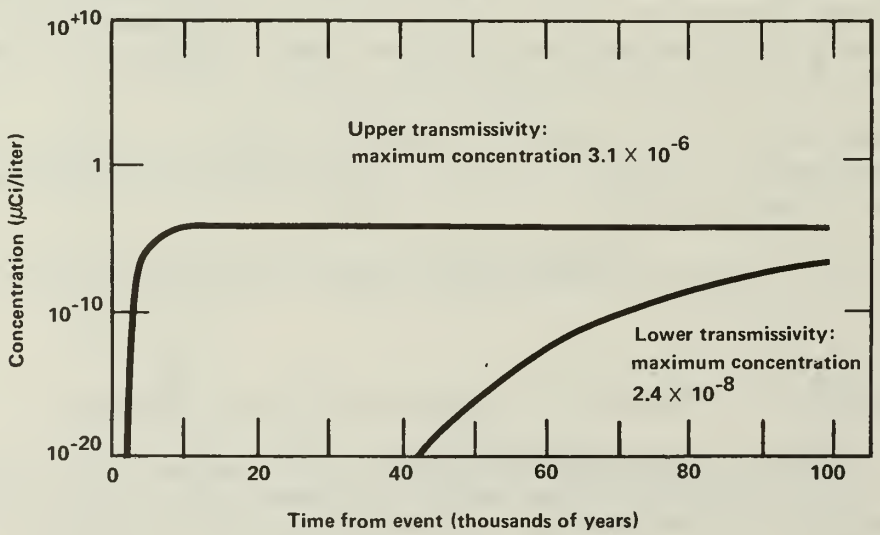

Figure 9-15. Concentration of all radionuclides in the Pecos River at Malaga Bend: scenario 1; event initiation, 1000 years; source of radioactivity, spent fuel.

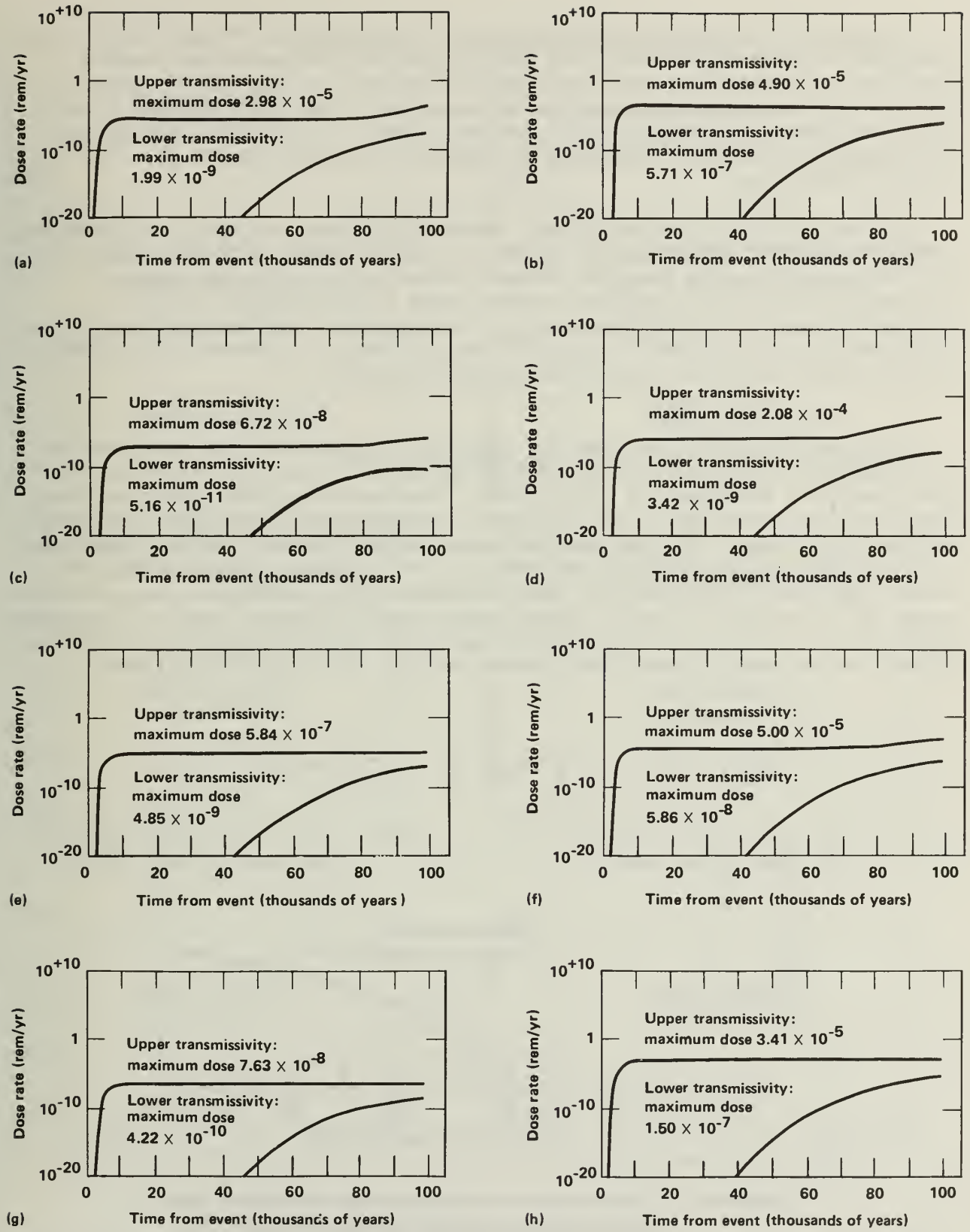

Figure 9-16. Doses from all radionuclides at Malaga Bend, scenario 1: (a) whole body, (b) thyroid, (c) skin, (d) bone, (e) liver, (f) kidney, (g) lung, (h) lower large intestine. Event initiation, 1000 years; source of radioactivity, spent fuel.

Release of CH TRU waste: consequences at Malaga Bend. Figure 9-17 shows the concentration history at Malaga Bend for radionuclides leaving the CH-waste repository after the events of scenario 1 take place. Under the lower-transmissivity assumption of scenario 1, the radionuclides do not reach Malaga Bend during the first 100,000 years. In contrast, the upper-transmissivity assumption produces a concentration near 100,000 years of 8×10^{-9} μCi/liter.

Figure 9-18 shows the calculated annual whole-body and organ radiation doses received by the maximally exposed person at Malaga Bend for scenario 1; the radionuclides come from the CH-waste repository. Only the upper-transmissivity data are graphed because there is no transport to the biosphere under the lower-transmissivity assumption. The maximum dose calculated is to the bone, 4.5×10^{-6} rem/yr. This is approximately 0.005% of the annual dose from natural background radiation.

Concentrations 3 miles from the repository. Radionuclide-concentration histories for the spent fuel and the CH TRU waste 3 miles downgradient from the repository are shown in Figure 9-19. The concentrations from spent fuel have attained steady state at 100,000 years under both assumptions on transmissivity. Steady state has been attained for the CH-waste contribution only with the upper-transmissivity assumption. The greatest concentration, which comes from spent fuel under the upper-transmissivity assumption, has a maximum value of 1.6×10^{2} μCi/liter. Other maxima occur for spent fuel at low transmissivity, 4.5 μCi/liter; CH waste at the upper transmissivity, 2.7×10^{-5} μCi/liter; and CH waste at the lower transmissivity, 1.2×10^{-12} μCi/liter.

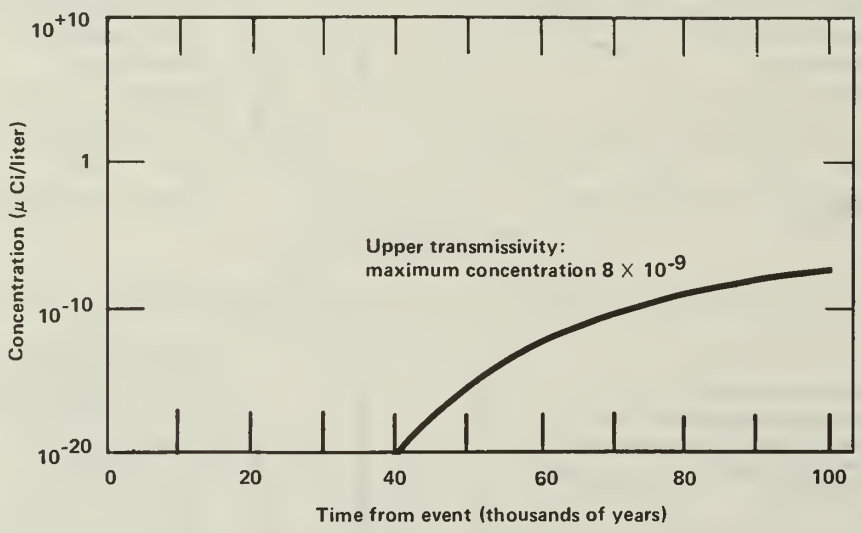

Figure 9-17. Concentration of all radionuclides in the Pecos River at Malaga Bend: scenario 1; event initiation, 1000 years; source of radioactivity, contact-handled TRU waste. Under the lower-transmissivity assumption, radionuclides do not reach Malaga Bend during the first 100,000 years.

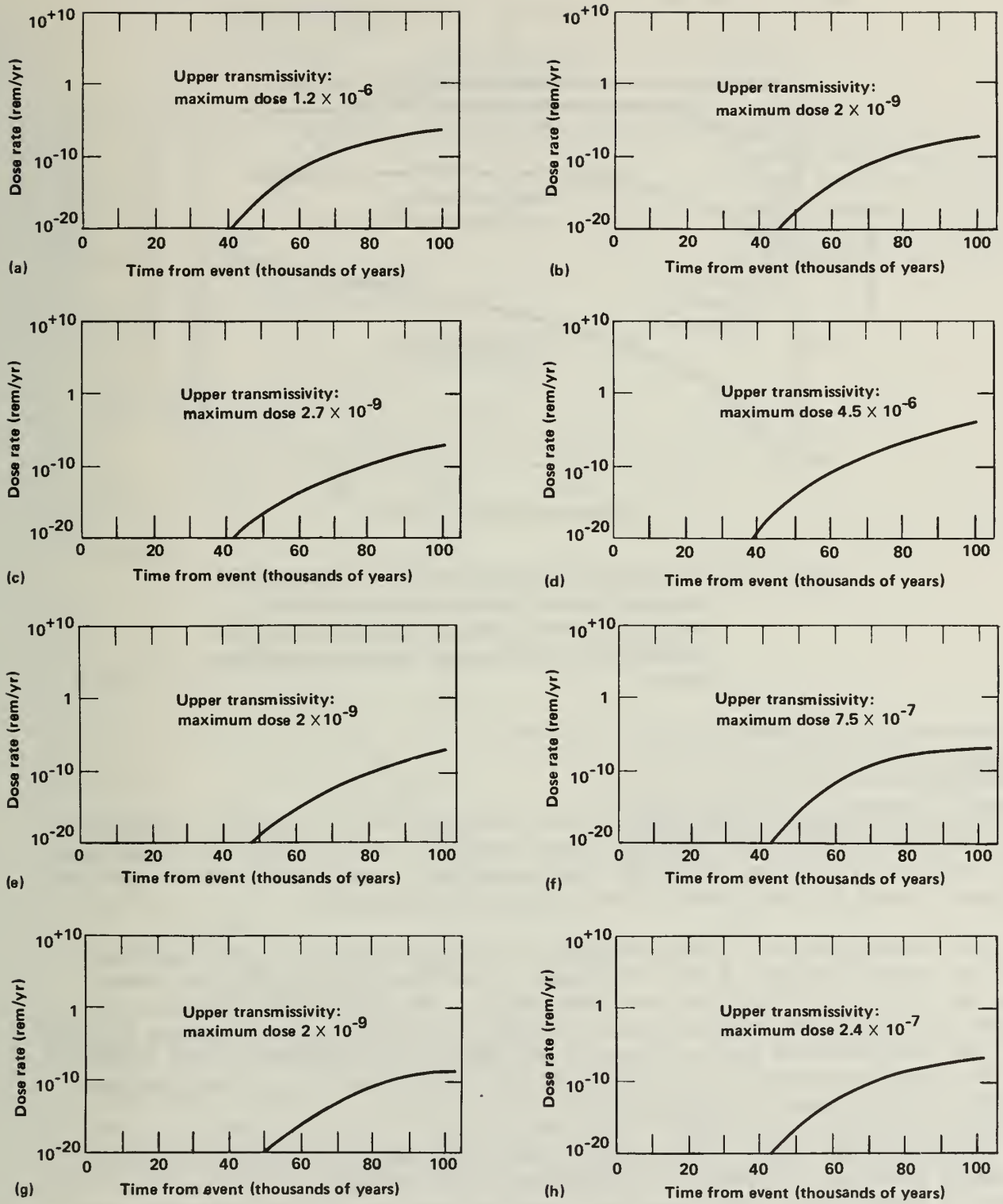

Figure 9-18. Doses from all radionuclides at Malaga Bend, scenario 1: (a) whole body, (b) thyroid, (c) skin, (d) bone, (e) liver, (f) kidney, (g) lung, (h) lower large intestine. Event initiation, 1000 years; source of radioactivity, contact-handled TRU waste. Under the lower-transmissivity assumption, radionuclides do not reach Malaga Bend during the first 100,000 years.

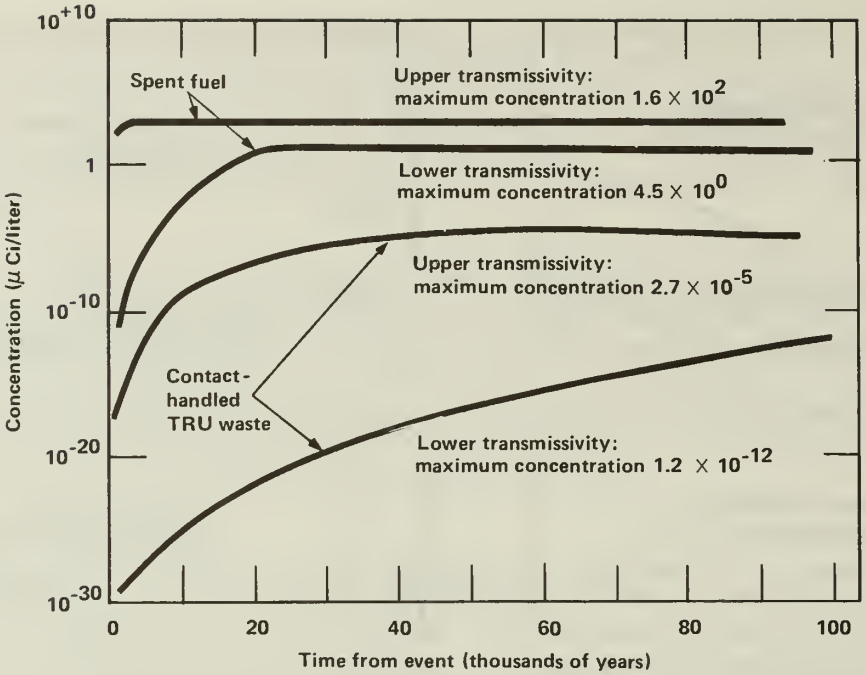

Figure 9-19. Concentration of all radionuclides in the Rustler aquifer at a point 3 miles from the repository: scenario 1; event initiation, 1000 years; source of radioactivity, spent fuel and contact-handled TRU waste.

Scenario 4

The worst scenario evaluated in this analysis is the bounding condition, an event in which all the Rustler waters normally moving above the repository pass completely through the spent-fuel repository. It is included to provide an upper bound to the impact of the reference repository.

The concentration of radionuclides in the Pecos River for the bounding case is given in Figure 9-20. The upper-transmissivity calculation shows a peak at 1.1 x 10^{-4} μCi/liter near 5000 years. The peak appears because the repository dissolves rapidly under the bounding conditions and because iodine-129 and technetium-99 are not delayed but move with the water to the river. At the lower transmissivity, iodine-129 and technetium-99 are dissolved more slowly, and the peak is absent.

Concentration histories at 0.14, 1, and 3 miles for cesium-137 for the bounding condition following a repository breach 100 years after sealing are shown in Figure 9-21. The important observations are the low 500-year peak at 3 miles and the rapidity of decay. The strontium-90 profiles are similar because the half-lives of these two fission products are nearly the same: 28.1 years for strontium-90 and 30.1 years for cesium-137.

The annual whole-body and organ doses received by the maximally exposed person are shown in Figures 9-22 and 9-23. The maximum dose of 2.09 x 10^{-3} rem/yr is to the bone. The maximum annual dose under the bounding case is less than 3% of the annual dose from natural background radiation.

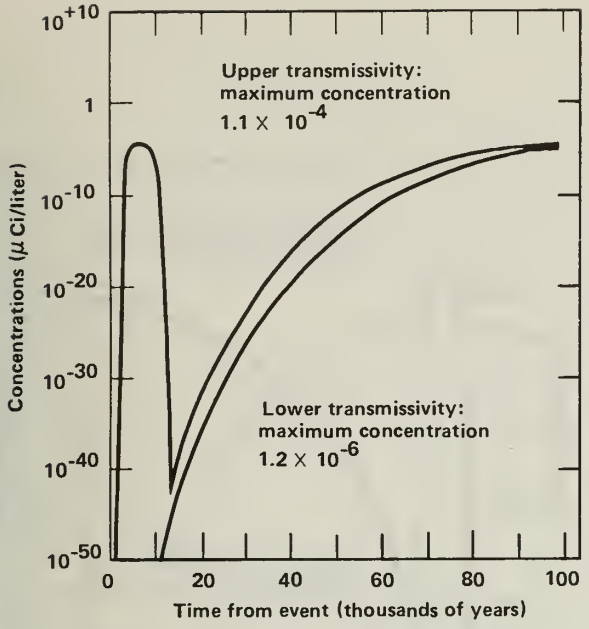

Figure 9-20. Concentration of all radionuclides in the Pecos River at Malaga Bend: bounding calculation (scenario 4); event initiation, 1000 years; source of radioactivity, spent fuel.

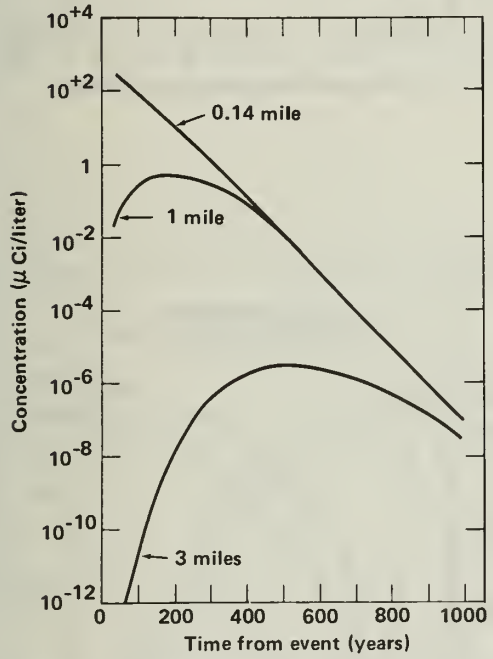

Figure 9-21. Time dependence of the concentration of Cs-137 in the Rustler aquifer at points 0.14, 1, and 3 miles from the repository: bounding calculation (scenario 4); event initiation, 100 years; source of radioactivity, spent fuel.

Summary for liquid breach and transport

The doses received by the maximally exposed person from scenarios 1 and 4 are small, compared to the annual average whole-body doses received by persons in the United States from various sources (EPA, 1972). This comparison is made in the following compilation (in units of millirem) for the year 1980:

Scenario 1	0.03
Scenario 4	0.4
Television	0.1
Consumer products	1.0
Air transport	1.0
Medical X-rays: abdominal dose	90
Natural background (reference site)	≃100

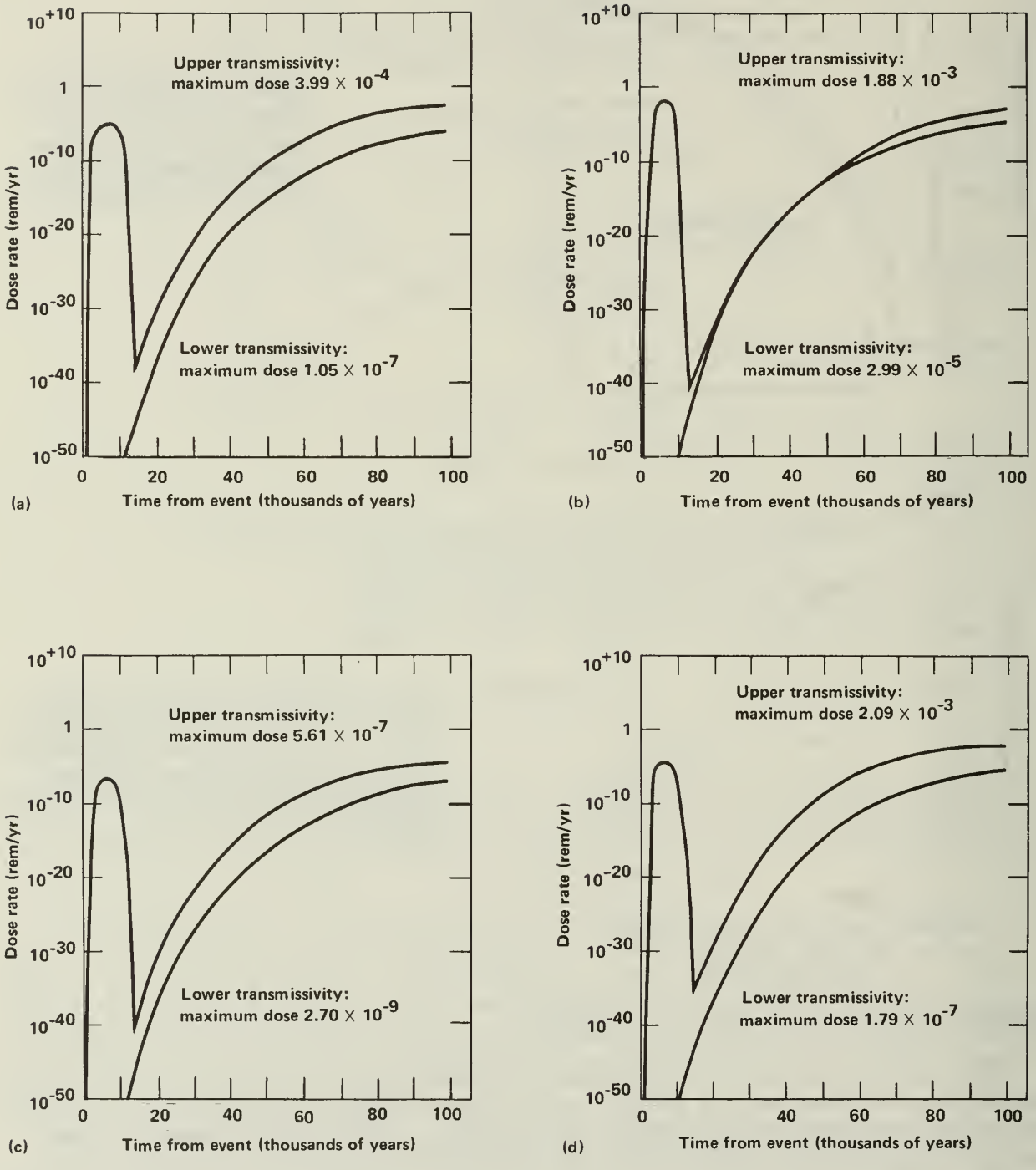

Figure 9-22. Doses from all radionuclides at Malaga Bend, bounding calculation (scenario 4): (a) whole body, (b) thyroid, (c) skin, (d) bone. Event initiation, 1000 years; source of radioactivity, spent fuel.

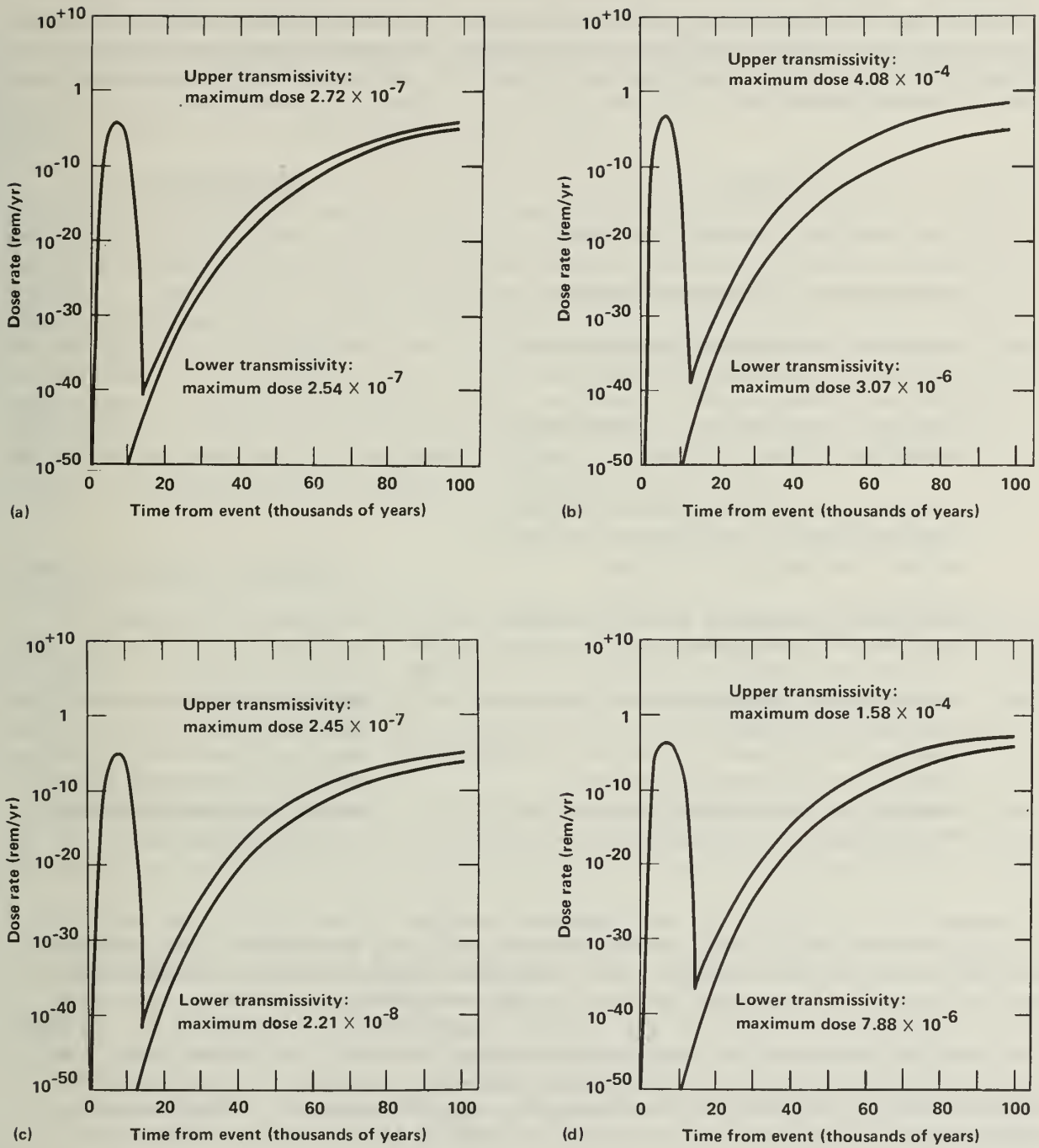

Figure 9-23. Doses from all radionuclides at Malaga Bend, bounding calculation (scenario 4): (a) liver, (b) kidney, (c) lung, (d) lower large intestine. Event initiation, 1000 years; source of radioactivity, spent fuel.

9.5.1.5 Scenario 5--Direct Access by Drilling

Scenario 5 was chosen to represent a worst-case situation in which people bring some of the repository contents directly to the surface. While the consequent radiation doses are high, the sequence of events that must occur in this scenario would be broken by the failure of any event in the sequence, which is listed below.

	Event	Consequence
1.	Institutional control is lost	
2.	Knowledge of the repository is lost	
3.	There is an economic incentive to explore in the area of the site	
4.	The repository area is chosen for drilling	
5.	The contents of the repository go unrecognized as radioactive material before and during drilling	
6.	Drilling intercepts a high concentration of radionuclides	
7.	The material brought up is left untreated and exposed	Drill crew receives dose
8.	The maximally exposed person remains in place continuously for for 1 year after drilling	Maximally exposed person receives dose calculated in this study

Scenario 5 is modeled in two separate studies. The first study models a well drilled for oil or gas, using today's drilling technology. It assumes a borehole 10 inches in diameter. The cuttings from the hole are mixed with an equal volume of drilling mud (a mixture of bentonite and barite); the total amount of material brought to the surface (approximately 100 tons) is assumed to be left at the site in a pit with a surface area of 720 square feet. At 10-foot intervals, the drillers collect down-hole samples for analysis: one side-hole core (1 x 3/4 inch) and one chip sample (2 grams). Two sets of these samples (0.1 liter per set) are assumed to be taken from the waste-repository horizons.

The second study models a hole drilled during exploration for minerals. It assumes a core drill 3 inches in outside diameter; this drill produces a continuous core 2.12 inches in diameter. The core, which contains 8 liters of contact-handled TRU-waste or 10 liters of spent fuel, is assumed to be retained and examined by a geologist. The drilling mud and cuttings are assumed to be left at the site in a pit with a surface area of 144 square feet.

External dose to drill-crew members

In calculating direct exposures received by the drill crew, the analysis examined current work practices to determine the amounts of time that drill crew members spend near samples. The greatest individual external dose is received by the geologist, who is assumed to examine the samples for 1 hour at an effective distance of 1 meter. The core and chip samples are treated as point sources with no self-shielding effects.

The doses for each of the direct-access scenarios, calculated as the maximum that an individual drill-crew member might receive, are shown in Table 9-47. The table shows these doses separately for drilling through the repository for contact-handled waste and for drilling directly through a spent-fuel canister. The latter event is highly unlikely because the cross-sectional area of 1000 canisters (about 1000 square feet) is much smaller than the area of the portion of the repository in which they will be stored (about 870,000 square feet). The highest dose occurs if the core sample from the 3-inch hole intercepts a spent-fuel canister after 100 years. This dose is calculated to be about 8.8 rem to the whole body, appreciably above today's standard for annual doses received by radiation workers (5 rem) but below the level at which any physiological evidence of exposure would result.

Dose via indirect pathways

In addition to exposure of the drill crew, the impact on individuals living near the site was evaluated. Water erosion of the mud pit, which delivers radionuclides to people primarily through the ingestion pathway, is ignored. In the arid region around the site, wind erosion is the dominant mechanism for the introduction of radionuclides into pathways leading to people. Such a pathway would deliver radionuclides principally through the inhalation pathway.

Details of the exposure calculations appear in Appendix K. Calculations of the airborne dispersion of radioactive material from the mud pit are based on measurements taken over 20 years at the GMX area of the Nevada Test Site

Table 9-47. External Doses Received by Drill-Crew Members from Chip and Core Samples

Borehole type	Waste type	Sample size (liters)	Whole-body dose (rem) 100 years	Whole-body dose (rem) 1000 years
Oil and gas (10-in. diameter)	CH TRU	2 x 0.1	3×10^{-5}	1.5×10^{-5}
	Spent fuel	2 x 0.1	0.18	0.028
Mineral exploration (3-in. diameter)	CH TRU	8	0.001	6×10^{-4}
	Spent fuel	10	8.8	1.4

(Healy, 1977). The air-suspension model parametrized for the Nevada Test Site observations and WIPP reference-site climate come from the NRC Reactor Safety Study (NRC, 1975).

Although at present there are no farms within several kilometers of the reference site, for this analysis it is assumed that a single-family farm exists 500 meters downwind from the mud pit. The farm is assumed to produce leafy green vegetables, dairy products, and beef. The people living on the farm are assumed to eat the food produced there and to breathe the air contaminated by the windborne particles from the pit.

For drilling through the contact-handled TRU wastes, the maximum calculated dose commitment (Table 9-48) is 3.6×10^{-5} rem to the bone; the dominating pathway is inhalation. This dose will be delivered if the release occurs from the mud pit associated with a 10-inch hole drilled 100 years after the repository is sealed. All the other doses in the table are well below this value.

Table 9-48. Maximum Dose[a] Received by a Person by Indirect Pathways After Direct Access to CH-Waste Repository

Pathway	Organ	Dose after 100 years (rem) 3-inch hole	Dose after 100 years (rem) 10-inch hole	Dose after 1000 years (rem) 3-inch hole	Dose after 1000 years (rem) 10-inch hole
Inhalation	Lung	2.0-7[d]	1.9-6	1.8-7	1.7-6
	Bone	3.6-6	3.5-5	3.3-6	3.2-5
	Whole body	9.3-8	9.0-7	8.2-8	7.9-7
Ingestion[b]					
Crops	Bone	1.5-7	1.5-6	1.3-7	1.3-6
	Whole body	4.5-9	4.3-8	3.4-9	3.3-8
Meat and milk	Bone	2.6-10	2.5-9	1.7-10	1.6-9
	Whole body	1.2-11	1.1-10	1.2-11	1.1-10
Combined pathways[c]	Lung	2.0-7	1.9-6	1.8-7	1.7-6
	Bone	3.7-6	3.6-5	3.5-6	3.3-5
	Whole body	9.8-8	9.4-7	8.6-8	8.3-7

[a] "Maximum dose" implies a 50-year dose commitment in rem from 1 year's intake by a person living at the corner of the farm nearest the drilling site and obtaining essentially all of his food from crops, milk, and beef raised at that location.

[b] "Crops" include fruits, grains, and vegetables.

[c] Combined-pathway doses include smaller contributions not included in the rest of the table.

[d] 2.0-7 = 2.0×10^{-7}.

The upper limit to doses calculated in this analysis appears in Table 9-49: the maximum 50-year dose commitment from spent fuel is 0.7 rem to the lungs, primarily as a result of inhalation. This is roughly 8% of the lung dose received in the same time from natural background radiation; the lung dose from natural sources in 50 years would be 9 rem (NCRP, 1975).

Table 9-49. Maximum Dose[a] Received by a Person by Indirect Pathways After Direct Access to Spent-Fuel Repository

Pathway	Organ	Dose after 100 years (rem) 3-inch hole	Dose after 100 years (rem) 10-inch hole	Dose after 1000 years (rem) 3-inch hole	Dose after 1000 years (rem) 10-inch hole
Inhalation	Lung	7.8-2[d]	7.0-1	2.0-5	1.8-4
	Bone	2.2-2	2.0-1	3.3-4	3.0-3
	Whole body	1.4-3	1.3-2	2.2-5	2.0-4
Ingestion[b]					
Crops	Bone	1.1-2	1.0-1	4.3-5	3.8-4
	Whole body	2.5-3	2.2-2	2.8-6	2.5-5
Meat and milk	Bone	3.5-3	3.2-2	3.0-7	2.7-6
	Whole body	8.9-4	8.0-3	2.0-8	1.8-7
Combined pathways[c]	Lung	7.7-2	7.0-1	2.0-5	1.8-4
	Bone	3.7-2	3.3-1	3.8-4	3.4-3
	Whole body	4.8-3	4.3-2	2.5-5	2.3-4

[a] "Maximum dose" implies a 50-year dose commitment in rem from 1 year's intake by a person living at the corner of the farm nearest the drilling site and obtaining essentially all of his food from crops, milk, and beef raised at that location.

[b] "Crops" include fruits, grain, and vegetables.

[c] Combined-pathway doses include smaller contributions not included in the rest of the table.

[d] $7.8\text{-}2 = 7.8 \times 10^{-2}$.

9.5.1.6 Summary of Calculated Doses

From this analysis, the following conclusions are drawn:

1. The greatest consequences from a nonbounding scenario are for scenario 1 at the upper limit on permeability. Under these assumptions, the greatest whole-body and organ doses are less than 0.3% of the whole-body dose from natural background radiation.

2. The highest whole-body and organ doses under the scenario 4 bounding-condition assumption for both spent fuel and contact-handled TRU waste are less than 3% of the whole-body dose from natural background radiation.

3. The scenario consequences depend strongly on the transmissivity of the Rustler Formation. The factor-of-20 difference between the flow rates for upper and lower transmissivities (Section 9.5.1.3) translates into a difference of many orders of magnitude between the maximum doses from contact-handled TRU waste. For the spent fuel, the effect of transmissivity is not so significant, but it usually translates into a difference of several orders of magnitude.

4. Under the lower-transmissivity assumptions, no contact-handled TRU waste enters the biosphere in the time frame considered for scenarios 1 through 4. Although the computer code will generate numbers, these numbers are effectively roundoff errors accumulated in the machine.

5. It is not considered likely that a drill crew would inadvertently drill into the repository only 100 years after sealing. If they did, however, the greatest external dose received by the drill crew is calculated to be less than 10 rem to the whole body under the assumption that the drill has penetrated a spent-fuel canister. This dose is equivalent to a 2-year dose at the limit currently allowed for continuously exposed radiation workers. If the drill should pass through the contact-handled TRU waste, the external dose is 10^{-3} rem. These two doses are reduced to 1.4 and 6 x 10^{-4} rem for an event 1000 years after sealing.

6. The indirect 50-year dose commitment for a person living on a nearby farm is conservatively estimated to be 3.6 x 10^{-5} rem to the bone if a drill penetrates the contact-handled TRU waste and 0.7 rem to the lung if it penetrates a spent-fuel canister. These calculated dose commitments are upper-bound values.

9.5.2 Effects Not Involving the Release of Radioactivity

9.5.2.1 Effects of Heat from Stored Waste

The effects of waste heat in the long term are greater in magnitude and extent than the limited effects described for the operational phase (Section 9.2.7). This section discusses the creation of buoyant forces that might lift the waste upward in the rock column, uplift of the rock column (and therefore the ground surface) due to thermal expansion, and change in the temperatures of the ground surface and the aquifers above and below the repository.

Calculations with the computer code STEALTH have investigated the thermomechanical effects that heat-producing waste might exert on the environment of the reference repository. The model represents the repository rock layers to a depth of 300 meters in a cylindrical volume of 400-meter radius. It uses actual laboratory measurements of the properties of the strata above and below the RH-waste repository; in this way the model accounts for the temperature-dependent physical properties of the rock layers. The salt is allowed to creep nonlinearly under stress. The spent-fuel repository is modeled as a 20-acre disk loaded to an initial power density of 30 kW/acre, which decays in time according to the heat-production rate of spent fuel. Details of the calculation are given by Maxwell, Wahi, and Dial (1978).

Figure 9-24 shows the long-term temperature response calculated from the model. At both the RH and CH levels, the temperature change caused by the spent fuel falls steadily after 500 years; at these levels no appreciable temperature changes appear at radii greater than 1 kilometer. At a depth of 41 meters from the surface the maximum temperature increase, about 0.1°C, occurs approximately 1000 years after emplacement.

Buoyancy

Figure 9-25 shows the effects of buoyant forces. According to these data, a point at the RH level first acquires a downward velocity and sinks about

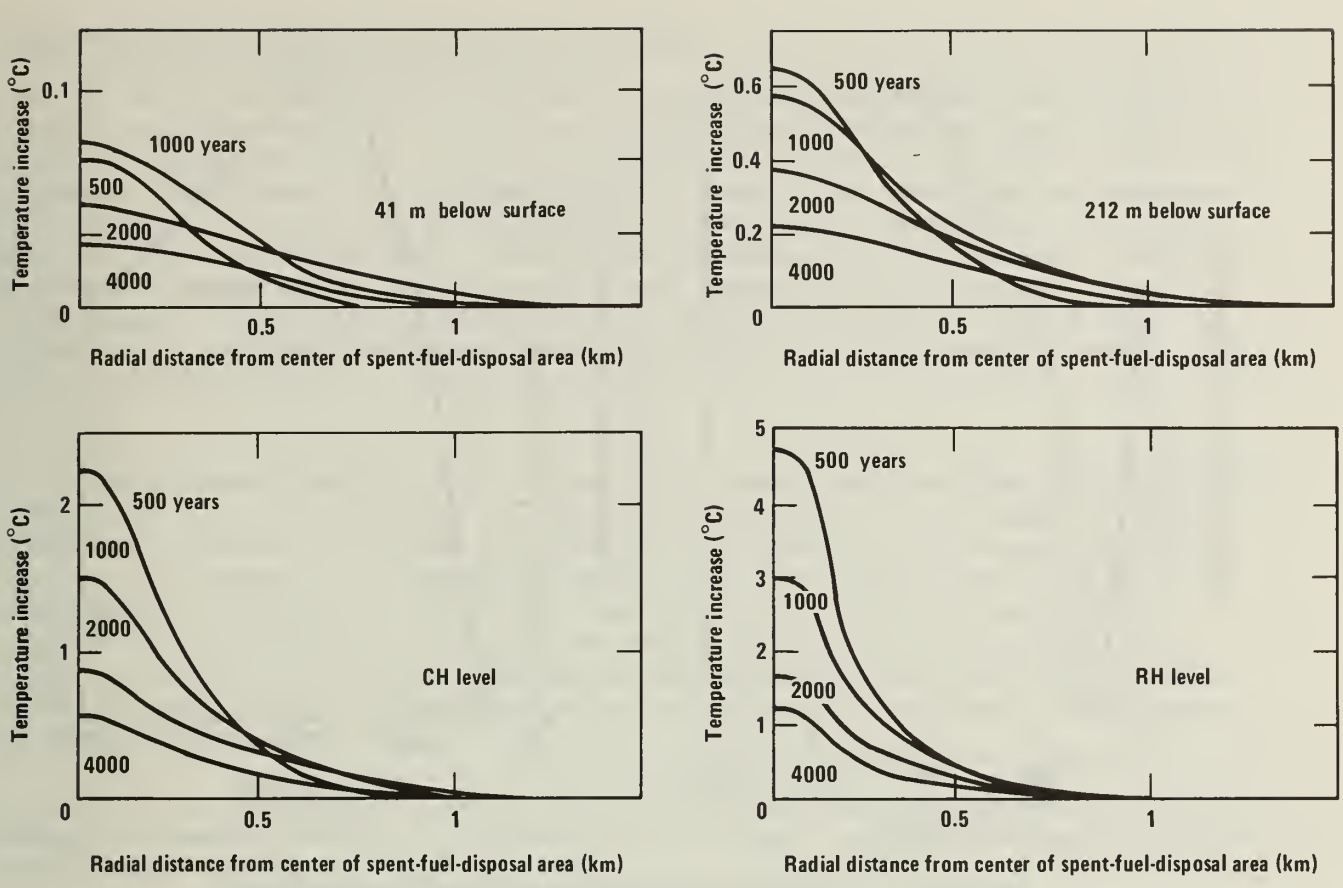

Figure 9-24. Temperature increase resulting from spent fuel.

2 centimeters before it acquires an upward velocity about 250 years after emplacement. Then the point rises; at 1000 years it is about 1 centimeter above its starting position. A point in the Rustler Formation will, according to Figure 9-25, rise to a maximum displacement of about 3 centimeters before sinking slowly toward its starting position.

None of the predicted displacements is large enough to lift the waste out of the salt into the overlying rock; about 560 meters of undisturbed evaporite rock lie above the storage horizon.

Surface uplift

The surface uplift predicted by the computer calculations appears in Figure 9-26, which shows the maximum uplift of about 3 centimeters occurring about 1000 years after emplacement. The uplift subsides slowly; at 3000 years it is about 1.5 centimeters. A surface uplift of 3 centimeters occurring over 1000 years would have little effect on the land or the rock strata above the repository.

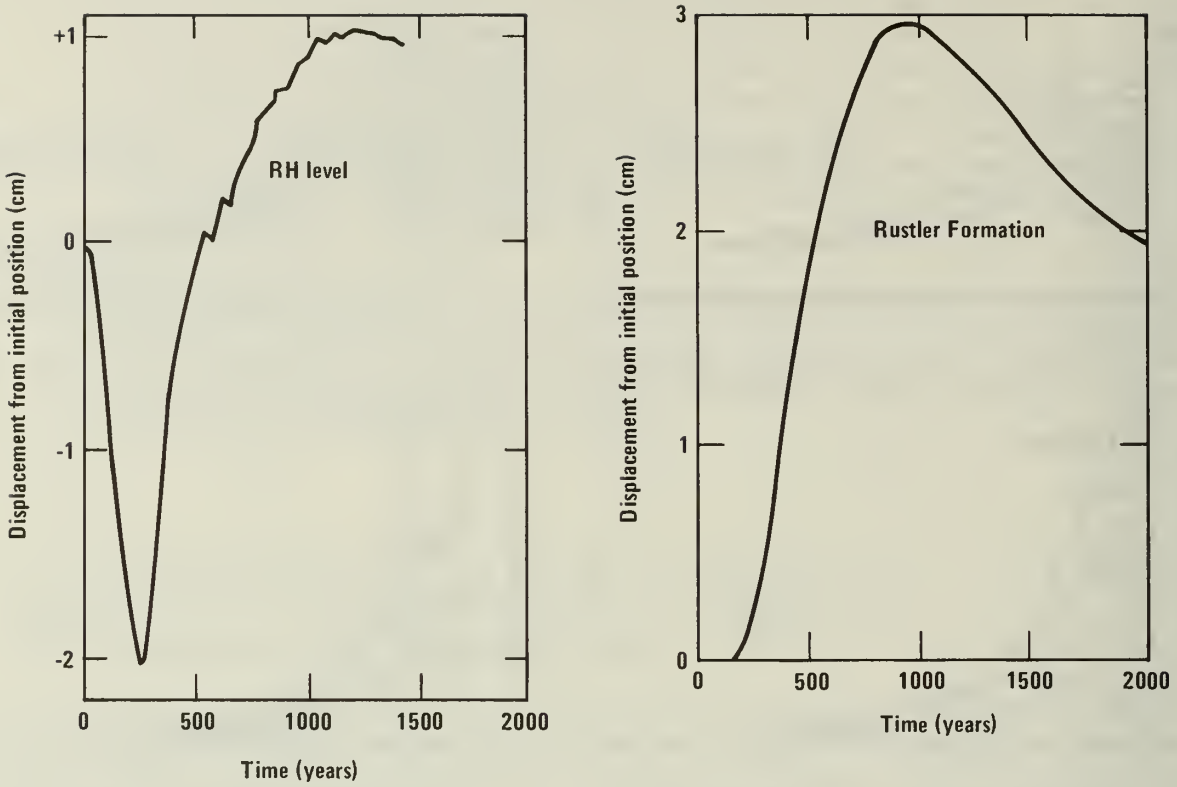

Figure 9-25. Predicted displacements resulting from spent fuel.

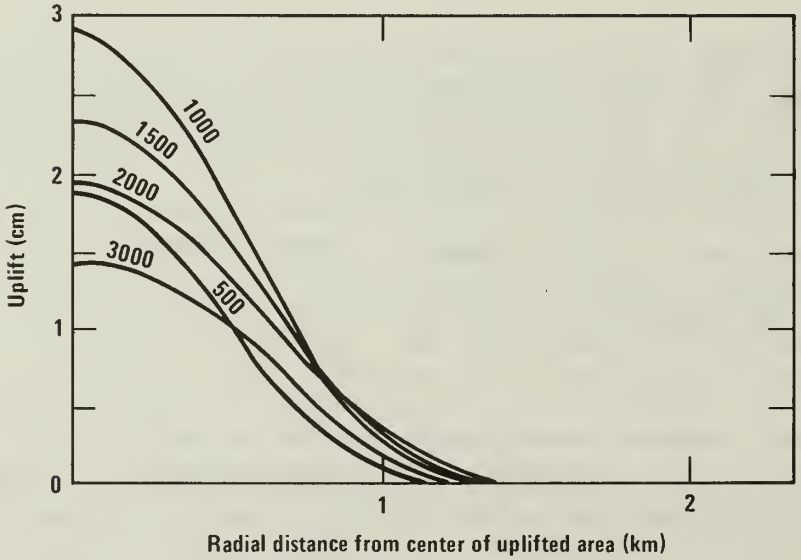

Figure 9-26. Surface uplift resulting from spent fuel.

Temperatures in aquifers and at the surface

As the heat emitted from the buried spent-fuel assemblies penetrates the repository surroundings, it will eventually reach the ground surface and the aquifers above and below the Salado Formation. Estimates of these temperature increases have come from a thermohydraulic model that describes the movement of released radionuclides in the geologic media by a finite-difference solution of the coupled pressure, energy, and mass-transport equations (Pahwa and Wayland, 1978). The transmissivity of the dominant water-bearing formations (the Magenta and Culebra aquifers of the Rustler) immediately above the repository is allowed to range from 1 to 20 ft^2/day. The water movement is toward the Pecos River, to the south-southwest.

Under the assumption that a 20-acre area at a depth of 2700 feet is loaded to an areal power density of 30 kW/acre, the model predicts that approximately 2000 years after emplacement the temperature increase in the Rustler aquifers will peak at about 3^oC. There is little or no effect on this peak increase from water expansion or from shutting off the slow flow in the aquifers. Uncertainty in the values for thermal conductivity of the rock surrounding the repository can introduce errors of as much as 50% in the calculated 3^oC rise. Currently under consideration is the problem of whether this temperature rise can affect the aquifers by producing anhydrite through dehydration of the gypsum present there.

Below the repository, the aquifer system that might be affected is in the Delaware Mountain Group. The temperature increase in these aquifers would be small, about 0.2^oC.

The maximum temperature rise at the ground surface will be about 0.02^oC, occurring after 2000 years. This rise can have no significant environmental effects. Over the long term there will be an apparent increase in the geothermal heat flux over the repository; it is not clear that this could have any effect on the environment.

9.5.2.2 Effects of Subsidence

The underground mined openings of the repository will eventually close because of the weight of the overlying rock and the plasticity of the salt. This section discusses the closure process and its effects at the surface and in the intervening rocks.

Collapse of underground openings is well known and has been extensively studied, especially in coal fields, but only as it affects mine safety and the integrity of surface structures. Both in coal mines and in potash mines, the surface area affected by subsidence exceeds the area of the underground openings. The angle between the vertical and a line connecting the edge of the surface subsidence and the edge of the underground opening is called the angle of draw; this angle is typically about 45° for potash mines near the WIPP reference site, which are shallower than the WIPP mine will be (BLM, 1975).

The rate of subsidence depends on the depth of the openings, the extraction ratio (area of the openings divided by area of the mine), and the nature of the overlying rocks. In potash mines, which have extraction ratios of over 80%, subsidence occurs soon after pillars are mined.

These principles can be applied to the WIPP reference repository. The surface area affected can be estimated by applying a 45-degree angle of draw to the area and depth of the underground workings. If the WIPP mine is assumed to contain 2000 acres at a depth of 2100 feet, this procedure suggests that subsidence will affect the ground surface out to a radius of slightly over 7380 feet, an area of about 4000 acres.

The following equation (General Analytics, Inc., 1974) was used to calculate the maximum subsidence:

maximum subsidence = (subsidence factor)(cavity height)(percent of cavity remaining after backfill)(percent extraction)

This equation assumes that the mine will be at the critical extraction width (the width of the area that must be extracted to produce maximum subsidence at the center of a subsidence trough); that it will have a subsidence factor (ratio of vertical surface displacement to cavity height) of 2/3, a figure from nearby potash-mining experience (BLM, 1975); and that it will have an extraction ratio of 30%.

Cavity heights of 16 feet would produce a subsidence of about 1 foot at 70% backfill and 1.6 feet at 50% backfill. These are maximum values over the center of the subsidence; they decrease from the center to the edge of the affected area, 7400 feet from the center.

Calculations of the waste-heat effects on room closure from creep (assuming a 30-kW/acre heat load) in Section 9.2.7 predict about 27% room closure in 25 years. The closure rate will be smaller in most of the RH-waste level, which is only a small part of the entire mine.

Nevertheless, cavity closure will proceed quickly on the geologic time scale; the resulting deformations will be quickly translated to overlying units. How the overlying units will respond to these deformations is not known in detail. The predicted surface subsidence of 1 to 1.6 feet will be insignificant inasmuch as the natural relief at the site is greater; furthermore, there is no integrated surface drainage to disturb.

In Nash Draw subsidences on the order of 200 feet are suspected to have created vertical interconnections between water-bearing strata in the Rustler Formation. Hydrologic testing has not yet determined whether this is true, but the possibility remains that to a lesser extent, because of the smaller subsidence, interconnections may also appear over the WIPP underground openings at the repository. Water from the Magenta and Culebra aquifers might then be introduced to the top of the Salado salt. That by itself would have little significance because of the 1200 feet of salt intervening between the top of the salt and the upper storage level. The question is rather to what extent fractures could penetrate down through the salt to the waste and stay

open. This possibility is basically scenario 3 of the containment-failure scenarios evaluated in Section 9.5.1. The calculated radiation doses resulting from that scenario are much lower than the doses from natural background radiation. Therefore subsidence, even when extrapolated to an extreme, would not significantly affect public health and safety or the ecosystem. Furthermore, water has not flowed into the local potash mines in spite of much more severe subsidence than the repository will experience.

Investigations of subsidence continue. A first-order level-line survey line was laid out in 1978 (Appendix J) to establish baseline elevations at the site and to monitor subsidence over certain active potash-mining operations. These field observations will help in developing a better understanding of the subsidence processes and in providing data for testing models. Other studies are now investigating the effects of subsidence on the surface, on the rock column, and on the aquifers.

9.5.3 Interactions Between the Waste and the Salt

Some of the unresolved technical issues in the analysis of waste disposal in bedded salt involve interactions between the waste and the salt. This section discusses the most frequently mentioned interactions. It summarizes the present state of knowledge about them, emphasizing their applications to the WIPP reference repository but leaving extended discussion to referenced documents when appropriate documents are available. Since investigations into the details of these interactions are continuing as part of the WIPP project, this discussion also mentions the programs now under way or planned.

9.5.3.1 Gas Generation

It is believed that stored nuclear waste may be able to generate substantial volumes of gas. Because contact-handled TRU waste sometimes contains organic and other gas-producing material, it has received closer scrutiny than remotely handled TRU waste or spent fuel. Nevertheless, all the types of waste might, in theory, release gases. There are two basic questions to be answered about gas generation:

1. How is the gas generated--by what mechanisms, in what amounts, and at what rates?

2. After generation, how will the gas affect the repository?

Mechanisms, amounts, and rates

Mechanisms so far identified for gas production from TRU waste are thermal degradation, radiolysis, chemical reactions, and bacterial decomposition.

The mechanisms for thermal degradation are pyrolysis and combustion; they have received considerable discussion in the literature (Godbee, 1972). Unfortunately, the data available were not collected in the temperature range of

interest to the reference repository. Some data suggest that there are threshold temperatures for pyrolysis (Murty, 1969). Because it is not clear whether these thresholds are real, some experiments in progress at the Los Alamos Scientific Laboratory (LASL) are establishing bounds for thermal degradation and catalytically mediated thermal degradation (Zerwekh and Kosiewicz, 1978).

Gas production by radiolysis is being investigated for unaltered TRU waste and for several matrices, including bitumen and concrete. Work at Los Alamos (Zerwekh and Kosiewicz, 1978) has shown that hydrogen production by alpha-particle radiolysis of unaltered TRU waste is similar to that by gamma-ray radiolysis of bitumen (OECD, 1976), about 3×10^{-3} cm^3/g-Mrad. There is at present an unresolved issue: whether radiolysis of solid material is self-limiting because radiolyzed material shields some water and organic molecules from further radiolysis. The corresponding problems associated with the radiolysis of concrete are discussed by Bibler (1977).

In gas production by chemical reaction, the reaction common to all TRU-waste forms is corrosion of the steel canister (Braithwaite, 1977). The reaction is thought to be $4H_2O + 3Fe \rightarrow Fe_3O_4 + 4H_2$; it is not believed to be temperature-limited. Although the capacity of a TRU-waste room is 15,400 barrels, or roughly 7×10^6 moles of iron (Sandia, 1977), only about 6×10^6 moles of water is available (at 0.5 wt%) from the crushed salt used to backfill a room and the associated tunnel. In theory, then, a maximum of 6×10^6 moles of hydrogen could be produced. The diffusion of water vapor through the porous backfill at 50% of the salt density is an open question. Other chemical reactions, which may depend on the waste form and on specific components in the waste, have not yet been characterized.

Bacterial decomposition is expected to occur only in unprocessed, unfixed TRU waste. There are a number of anaerobic halophilic bacteria that will be introduced with the waste, particularly if unsterilized biological products are in it. Nothing in the repository environment--including the salt, radiation, temperature, or brine--is known to inhibit the bacteria (Kuznetsov et al., 1963; Parnas, 1975). It has, however, been suggested that the growth of bacteria in the mine may be limited by the absence of sufficient quantities of certain nutrients, such as nitrogen (Leckie and Halvadakis, 1975). It is unclear whether such limitations will affect the total gas production or merely the rate of production. The problem is under study at the University of New Mexico and at Los Alamos.

The potential for bacterial gas production can be estimated by examining data from old landfills (James, 1977). To a reasonable degree TRU rubbish approximates the composition of household refuse if the small amount of wet household garbage is discounted. The gases produced in landfills tend to be mixtures rich in methane and carbon dioxide, produced in volumes like 450 m^3/tonne of refuse.

Current observations suggest that the bounds on gas production by pyrolysis and bacterial decomposition are less than 500 m^3/tonne, or about 2.2×10^4 moles per tonne; for radiolysis they are less than 50 m^3/tonne, or about 2.2×10^3 moles per tonne.

Gas could also be produced from the high-level waste used in WIPP experiments and from remotely handled TRU waste. It could arise from chemical reac-

tions of the waste containers with brine, if any brine is available, and from the radiolysis of waste inside the containers. Radiolysis is known to produce only about 0.1 cubic centimeter of hydrogen per calorie of energy stored in the salt (Jenks and Bopp, 1977). Since the hydrogen would be released on dissolution of the salt, the amount of gas produced by these wastes could be estimated from the chemical reactions alone--that is, from the mass of iron in the canister.

Spent-fuel assemblies can possibly release fission-product gases, in addition to the gas produced by chemical decomposition of the containers. If spent fuel is kept in storage pools for at least 10 years after removal from the reactor, the principal gases produced will be tritium, krypton-85, iodine-129, and radon-222. The amount of gas will depend on the treatment of the fuel-rod bundles for shipping and on their containers.

Effects of evolved gas on a repository

The void volume left behind in a sealed repository will be about 50% of the original mined opening because the backfill salt will be at a density about 50% of the rock-salt density. As the salt flows under lithostatic pressure, this open volume in the repository will close, probably in 50 to 200 years (Baar, 1977, p. 136). Closure to full salt density is expected because the air in a room and tunnel is only 4×10^5 moles, not enough to maintain appreciable openings in the salt. Nevertheless, some volume may become available for storing evolved gas because of dilatancy (Jaeger and Cook, 1976, p. 85): as the salt creeps into openings in the repository, it is at a reduced density. Gas evolved from the waste could compress the salt back to full density, creating gas-filled volumes that might amount to roughly 10% of the volume that the creeping salt had filled.

While mine closure may be complete in 200 years, gas may evolve from the waste over much longer times; gas production will apparently be slow compared to mine closure. Depending on the permeability of the salt, the gas may disperse in at least one of three possible modes:

1. The medium is permeable enough to allow gases to move away from the repository without any significant pressure buildup.

2. The medium is impermeable, and gas accumulates until the medium fractures under the gas pressure.

3. The medium is impermeable, but the gas accumulation is sufficiently slow for the medium to flow plastically, adjusting the void volume; the pressure never becomes much more than lithostatic, and the medium remains intact.

The first of these modes has been tested by a mathematical calculation. The model used in the calculation describes the diffusion of gas from a repository, represented as a plane source, through the overlying salt, represented as a flat slab. A computer code incorporating the model provides numerical solutions for the equations describing the diffusion process, the boundary conditions, the coupling between gas concentrations in the repository and in

the overlying salt, and the time dependence of the evolved gas volume. Because the most likely modes of gas production have not yet been determined, gas-production rates were assumed, in separate calculations, to have time dependencies that roughly simulated different modes of production; the total volumes of gas produced were taken from data on gas produced in landfills. The equations were solved for values of salt permeability lying between 10^{-5} and 10^{-12} cm^2/sec (between 0.2 and 2 x 10^{-8} microdarcy). In all the calculations the gas production was allowed to persist for 100 years, and the solution of the equations was carried out to 300 years.

Even at the largest assumed permeability, the calculations predicted that gas pressures might exceed lithostatic pressures at the repository depth. In other words, the first of the three dispersal modes does not appear likely; the salt above the repository is not so permeable that gas, if produced, is sure to diffuse away without a significant pressure buildup.

Because the calculations had to use hypothetical rates and volumes of gas production, the results cannot be considered accurate predictions of the effects of gas evolution. Experimental programs now under way are investigating gas production, and in approximately 2 years accurate values for rates and volumes will be available. Until these data are available, it will be prudent to assume that the permeability of salt is not great enough to prevent significant pressure buildup above a repository. To insure that evolved gases will not fracture the rock overlying the reference repository, the waste-acceptance criteria will limit the amount of gas-producing material in the waste accepted for burial.

9.5.3.2 Brine Migration

A number of papers on the movement of fluid inclusions in alkali halide crystals have drawn attention to the possibility of similar movement by the naturally occurring brine inclusions in the bedded salt of southeastern New Mexico. Laboratory experiments and theoretical analyses performed so far (Anthony and Cline, 1974), as well as the one field experiment (Bradshaw and McClain, 1971; Bradshaw and Sanchez, 1969), are idealizations of the problem of fluid-inclusion movement in the thermal field of high-level or other heat-producing waste. According to experimental studies, these movements depend on thermal gradients and are credible only for sources with a substantial thermal power output. Therefore, these effects are not appreciable for TRU waste in the WIPP reference repository, though they may be for spent fuel, depending on its thermal output. If the effects are appreciable for spent fuel, they will have to be taken into account in plans for retrieval.

Description of the problem

Because of the idealizations involved in the work already published, it is necessary to describe in some detail the physical situation in the vicinity of canisters containing heat-producing waste.

The initial conditions are established with the driving of the drift in the salt and the drilling of the emplacement hole for the waste canister. This excavation produces a free surface that is no longer at a lithostatic

pressure of 150 to 200 atmospheres, but rather at about 1 atmosphere. Thus there is a stress-relieved region around the emplacement hole, normally containing an abundance of microcracks extending a short distance into the medium. After a waste canister or a spent-fuel sleeve is inserted, the remaining volume is backfilled to improve thermal contact with the walls of the canister, and a plug seal is placed over the canister. The initial surface temperature of the canister is between the free-air temperature and the temperature at which the canister and the salt will equilibrate in the short term.

The salt now experiences a time-dependent thermal load that raises the temperature of the salt and accelerates plastic flow in the vicinity of the canister. This creep continues until the stress returns to the lithostatic value; the pressure in the vicinity of the canister begins to return to what it was before disturbance. In the short term, the effects due to changing temperature dominate the effects due to changing pressure.

It is known experimentally and theoretically how and under what circumstances inclusions move up and down the thermal gradient. If inclusions reach the canister, they will probably affect the rate of canister corrosion and subsequently the leach rate of the waste. It has been suggested that, if enough fluid accumulates in a heated zone, the local structural properties of the salt will be altered (Bredehoeft et al., 1978). The size of the zone in which fluid accumulates can be estimated roughly from the amount of water available per unit volume of repository salt and from estimates of the amount of solid material per unit amount of fluid material required to form eutectic mixtures (Stewart, 1978); the width of the zone of expected structural alteration around a canister would range from a few centimeters to, at most, a few tens of centimeters. It has been further suggested (Anthony and Cline, 1974) that when inclusions reach the waste their gas fraction could be altered enough to make them move back down the thermal gradient, away from the heat source. Of these possibilities, the corrosion and leaching properties are currently under study in the laboratory (Sections 9.5.3.3 and 9.5.3.4). The phase alterations and structural consequences thereof are under investigation by the Office of Nuclear Waste Isolation and by the U.S. Geological Survey, which is also characterizing the brine inclusions in salt at the reference site and determining their history. Sandia Laboratories is investigating the movement of inclusions. Whether in fact any radionuclides can be mobilized by a moving fluid inclusion is unknown and is being studied at the Argonne National Laboratory.

Known effects

In laboratory studies (Anthony and Cline, 1974), fluid inclusions with less than 10% gas are observed to migrate up the thermal gradient toward the heat source. Large inclusions break into two or more small inclusions with different distributions of gas and liquid and with different rates of movement. The inclusions move up the thermal gradient because the solubility of sodium chloride in water increases slightly with temperature. Since the end of the inclusion closer to the heat source is warmer, dissolution proceeds at the closer end with precipitation at the farther end; the inclusion moves toward the heat source.

Fluid inclusions containing vapor are observed to migrate down the thermal gradient away from the heat source. Water evaporates at the hot end of the

inclusion; the vapor moves to the cooler end and condenses, dissolving salt in the unsaturated water. The inclusion thus moves away from the heat source.

Boundary and initial conditions

In analyses done so far, the changing thermal field has been approximated by a constant gradient. The actual phenomenon takes place in a time-dependent thermal field; according to estimates based on simple calculations, the heat from an emplaced canister will, within a few months, increase the heat load at the next emplacement hole in the array. The thermal gradients around the canisters will shortly thereafter become so uniform that inclusions will cease to migrate.

Furthermore, no consideration has been given in past analyses to the changing pressure field. Since the amount of vapor in an inclusion will depend on both the temperature of the fluid and the confining pressure, so will the direction of motion.

Bounds on migration

Anthony and Cline (1974) obtained their results on the velocities of brine-inclusion travel at a much higher thermal power than the spent-fuel demonstration will produce at the WIPP reference repository, where the temperature at the salt-canister interface will be less than 100°C. Their experimental work was for a temperature gradient of 3 K/cm, but they also present data at lower gradients. The velocity of inclusion movement falls drastically as the gradient decreases and is essentially zero at 10^{-3} to 10^{-4} K/cm, which is the geothermal gradient. (If the movement did not fall to zero, there would be no fluid inclusions in natural salt.)

According to the calculations of Fewell and Sisson (1977) for a canister hotter than those at the WIPP, the initial gradient is greater than 3 K/cm close to the canister, about 1.3 K/cm over the first 30 centimeters outside the surface of the canister, and about 0.3 K/cm at 1 meter. At the velocities determined by Anthony and Cline for 3 K/cm, only an inclusion within the first 30 centimeters could reach the canister in a year. The total volume of water in fluid inclusions within such a region is about 7.5 liters per meter of canister length when the canister radius is about 15 centimeters.

As mentioned earlier, the actual situation will be more complicated. If, for example, microcracks appear close to the canister, where salt becomes hot soonest, they will allow venting of the inclusions when steam comes into contact with the canister. Another complication may occur as the thermal load moves into the salt: the nongassy inclusions will move toward the canister while the gassy inclusions will move away. Since the confining pressure in the salt decreases toward the canister, some of the nongassy inclusions will, when heated, become more gassy and reverse their motion. Eventually, as the pressure near the emplacement hole increases to the lithostatic value, any fluid inclusion will remain fluid at the local temperature.

In summary, the experimental results presently available suggest that the following phenomena are likely:

1. Gassy inclusions (inclusions containing condensable gases) move down the thermal gradient away from the heat source.

2. Nongassy inclusions may move to the region around the canister-emplacement hole where microcracks are usually present; there these inclusions may vaporize.

3. Nongassy inclusions may first move toward the canister and then move away.

4. After a short time, less than a year, the temperature field around an assemblage of canisters will have become so uniform that the weak thermal gradient will bring no more inclusions to the canisters during the period of high heat production.

5. At some distance (10 to 100 centimeters) from the canister, there will probably be a halo of fluid inclusions immobilized in the weak thermal gradient.

6. In the absence of more extensive experimental data, the total volume of fluid drawn to any canister can be estimated only crudely; it may lie between 0.1 and 20 liters, with 0.1 liter more likely (Anthony and Cline, 1974).

Rigorous verification of these expectations will require further investigations. Brine migration has not yet been studied in its entirety, either experimentally or theoretically. Current knowledge is sufficient to predict, however, that brine migration will not significantly affect the repository, because little of the waste stored there will produce significant thermal gradients.

Further research under WIPP auspices will provide data that will be useful in detailed analysis of the effects of remotely handled TRU waste and in the design of future repositories for high-level waste. Laboratory and bench-scale work has been under way for a year. Experiments are also planned for salt in a mine, where the lithostatic pressures and boundary conditions will approach those to be encountered in the WIPP repository. After the reference repository opens, experiments on brine migration will be carried out there (Section 8.9).

9.5.3.3 Canister Corrosion

There are several purposes for waste containers: they are indispensable in waste processing, temporary storage, transportation, and other physical handling. The waste container is not intended, however, to be the major barrier preventing radioactive materials from entering the biosphere. The burial medium is the most significant barrier, for the geologic structures surrounding the waste provide a container several thousand feet thick. In the long term, hundreds to thousands of years, corrosion resistance by the canister is of minimal importance.

In the short term, corrosion resistance is important in being able to retrieve the TRU-waste containers and spent-fuel canisters to be emplaced at the repository. Ease of retrievability has therefore been the major focus of corrosion studies related to the WIPP project because there are no accurate data

on the amount of brine required to corrode containers over the 10-year period of retrievability. Corrosion resistance can be provided by the choice of metal alloy, by anticorrosion coatings such as paints and ceramics, and by overpacks made of metal or ceramics, either alone or in combination. Laboratory studies on these topics are in progress.

Examination of mild-steel canisters holding low-level waste in the salt repository at Asse, Germany, revealed minimal corrosion after periods of up to 12 years (Sattler, 1978). Corrosion of contact-handled waste canisters in the dry WIPP salt is expected to be similar. Retrieval of contact-handled waste in intact canisters is, therefore, expected to pose no problems at the reference repository.

To insure efficient retrieval of canisters from the spent-fuel demonstration and the experiments with high-level waste, corrosion of canisters and canister liners holding heat-producing waste needs to be quantified further, both in dry salt and in a concentrated-brine environment. This effort is the focus of a large fraction of the WIPP corrosion studies (Molecke, 1978), and similar studies are being conducted at the Savannah River Plant (Angerman and Rankin, 1978). Another effort now under way is the engineering design of apparatus that can retrieve high-level waste even if the metallic canister has corroded away (Sandia, 1977).

Also in progress are laboratory feasibility studies to develop canister materials with a lifetime of several hundred years. Such materials could prevent radionuclide leaching and migration if water were to breach the repository during the time when the thermal output of the waste is high enough to enhance leaching.

A program of metallurgical and materials studies is now evaluating materials for use in the WIPP and other repositories. The results will help in selecting materials with adequate mechanical strength and thermal conductivity. These materials may be used in canisters, overpacks, anticorrosion coatings, sampling apparatus, instruments for experiments, and other mine equipment. As much as possible, the studies will use existing metallurgical data, although little existing information applies to the conditions expected in the high-level-waste experiments: temperatures of up to 250°C, pressures of up to 180 atmospheres, a radiation field, and saturated brine. The data gathered by Braithwaite (1978) and by Angerman and Rankin (1978) are the most pertinent.

The schedule for corrosion studies extends from the present through the early part of repository operation. Laboratory studies at Sandia Laboratories (Molecke, 1978) will be essentially complete in several years. Associated work is in progress or planned at other laboratories. Bench-scale corrosion studies begun in 1977 are continuing; evaluations in a potash or salt mine will begin in 1979, and corrosion results from the Asse mine will be compared with the results of the other studies. The final testing of canister materials will begin with the first acceptance of waste packages at the WIPP mine. The results of all these programs will be made public as they become available; initial results have already been presented (Braithwaite, 1978; Rankin, 1978).

9.5.3.4 Leaching

The leachability of nuclear waste could be important to the WIPP reference repository because leaching of the waste by water or brine would have to take place before intruding water could mobilize radionuclides. Although the intrusion of water into the WIPP storage areas is of very low probability, it is the basis for the most credible scenarios describing the release of radionuclides from the sealed repository (Section 9.5.1). Interactions between the waste and dry salt could also be important because they might, in theory, enhance or retard leach rates. Other conditions that could affect leaching are radiolysis of any brine that might be present, rock constituents other than sodium chloride, corrosion products of the waste containers, lithostatic pressure, and elevated temperature.

Consequence analysis is the principal tool for predicting the long-term importance of leaching; experimental data on leaching and interactions with dry salt are desirable inputs to the study. The consequence analysis in Section 9.5.1 assumes that water removes radionuclides from waste at the same rate as water dissolves salt. It makes this unrealistic assumption because directly applicable data are not available. When experiments have provided the necessary input data, the analysis can become more realistic and less conservative. It is significant, however, that the analysis in Section 9.5.1 predicts that the WIPP reference repository would produce no serious long-term effects even if leaching occurred as rapidly as salt dissolution.

Much research in leaching has already been performed. The leachability of matrices proposed for encapsulating radioactive waste has been a subject of study for many years in the United States, Europe, and Japan. In fact, the durability of radioactive-waste forms is often specified by leach-rate measurements. Because collections of these data and discussions of their significance are readily available (Katayama, 1976; ERDA, 1977; Scheffler and Riege, 1977), they are not reviewed here.

Most of these data were obtained under laboratory conditions that did not resemble conditions at the reference repository. Applying them to the specific geologic conditions of the repository will require additional study. Moreover, some questions not addressed in studies to date are of interest to WIPP analyses and to the design of future repositories for high-level waste. Experiments to answer these questions will be performed over the next several years in both laboratory and in-situ studies (Molecke, 1978). Because high-temperature, high-pressure data are not available, the leaching of waste matrices is being tested under conditions representative of the repository: a leachant in the form of concentrated brine or groundwater, temperatures of 25 to 250°C, and pressures of up to 180 atmospheres.

Laboratory data will be used to formulate models that predict leaching behavior over hundreds to thousands of years. The models will then be tested in the laboratory under accelerated conditions; they will be retested in the WIPP in-situ program (Section 8.9). The results of these studies and interpretations of their significance will be made available as the experimental programs develop further.

9.5.3.5 Stored Energy

An often-raised question is whether energy stored by radiation damage in the salt surrounding buried waste or in the waste matrix could be released and produce a serious thermal excursion or some other undesirable effect. This problem has been under study at the Oak Ridge National Laboratory (ORNL) since 1970; the arguments and conclusions presented here are based primarily on data collected there.

Of the alpha, beta, gamma, and neutron radiation emitted by the waste, only gamma rays and neutrons enter the salt. In the absorption process the radiation interacts with the crystal lattice of the salt to produce radiation damage. The gamma-ray interactions primarily produce electron vacancies when the photons excite chlorine electrons into the conduction band. By a series of processes the lattice adjusts, and energy is stored in the crystal structure; the subject is discussed in an ORNL report (Jenks and Bopp, 1974). The interaction with neutrons is likely to store energy by producing ionic displacement directly in the crystal lattice. Extensive studies at Oak Ridge (Jenks and Bopp, 1974) have shown that energy stored by either process can be released by annealing the salt at a temperature above 150°C; little energy from radiation damage is stored above that temperature.

Contact-handled TRU waste, which is the primary concern of the WIPP reference repository, has virtually no gamma output--less than 10 mrad/hr from 200-liter drums. The actinide limit as determined by INEL inventory has been less than 10 grams of plutonium per drum during the years for which the inventory is available. With the mix of plutonium isotopes assumed for contact-handled TRU waste (Appendix E), this limit suggests a maximum dose rate of 1.6×10^{-4} rad/hr for neutrons (Bingham and Barr, 1979).

Contact-handled TRU waste is placed in large rooms. Even after total closure of the mine and compression of the waste, the material remains in bulk, approximately 15 by 130 by 1 meter; the only major contact with salt is along the outside of the bulk material. Since the relaxation distance for both gamma and neutron radiation is 10 to 15 centimeters, most of the stored energy from radiation damage is located inside the waste matrix. At the dose rates expected for TRU waste (less than 10 and 0.16 mrad/hr for gamma rays and neutrons, respectively), the total dose over 1 million years is less than 10^8 rads. This dose will produce stored energy in the waste matrix and salt at a concentration lower than 1 cal/g, an insignificant amount (Jenks and Bopp, 1977, Figure 6; Jenks, 1975, p. 3). Temperatures in contact-handled TRU waste, which produces essentially no heat, never rise to the annealing temperature of salt.

No studies of energy storage near heat-producing wastes are directly applicable to the reference repository; these analyses have so far been performed only for high-level waste. Because the effects of high-level waste are generally upper bounds on the effects of spent fuel and remotely handled TRU waste, this discussion reports predictions from the available studies. Qualitatively, these remarks will apply to spent fuel as well as to high-level waste.

The waste configuration assumed here is the one defined by Zimmerman (1975), reduced to 3.5 kilowatts: a canister 30 centimeters in diameter and about 3.5 meters long with a thermal output of about 3.5 kilowatts and surface

dose rates of about 2×10^5 rad/hr for gamma rays and about 40 rad/hr for neutrons. These parameters describe reprocessed PWR fuel 10 years out of reactor.

In the burial configurations now under study, a high-level-waste canister is in intimate contact with salt and is separated from other canisters by distances much greater than the relaxation length for gamma-ray penetration into the salt. This length is about 15 centimeters; in 30 centimeters, about 90% of the gamma radiation has been absorbed. In addition to the radiation damage in the salt, there is radiation damage in the waste matrix. Inside the canister, however, temperatures are above the so-called annealing temperature, and most of the radiation damage is healed. A similar annealing phenomenon occurs in the salt, reducing the total energy stored. Temperature profiles (Jenks and Bopp, 1974) show that the temperature in the salt remains higher than 150°C at distances of four relaxation lengths (about 60 centimeters) for times longer than the half-life of the primary heat-producing nuclides, cesium-137 and strontium-90. After adjustment to a maximum of 60 cal/g (the maximum stored energy) and expansion to 60 centimeters, the total amount of energy stored beyond 60 centimeters is negligible (Jenks and Bopp, 1974, Figure 8). The average energy stored in the salt is about 3.5 cal/g.

The same document discusses the mechanical and structural consequences of the sudden release of this energy by annealing and concludes that they would be "practically negligible."

In addition to annealing, there is another possible means for sudden release of the stored energy: dissolution of the salt. Release by this mechanism produces a minor temperature change because at least 2 cubic centimeters of fresh water is required to dissolve 1 cubic centimeter of sodium chloride. The dissolution process is somewhat autocatalytic since the solubility of sodium chloride depends on temperature, increasing slowly as the temperature rises. On the average, however, particularly if there is any convective motion in the fluid dissolving the salt, the average temperature change in the fluid is about 2°C, a temperature excursion that does not threaten catastrophe.

This discussion has disregarded a more complex problem: the formation of multiphase systems with impurities in the salt. (The term "multiphase" is used here in the sense used in physical chemistry, where it refers, loosely speaking, to systems consisting of many discrete components in various states of matter.) While this process does not affect the thermal release, it raises other questions concerning chemistry and density. During dissolution the presence of hydrogen produced by radiolysis may be a factor in reducing further intrusion of brine or water into the vicinity of the canister unless the intrusion has been massive.

Remotely handled TRU waste, which will probably be emplaced in a manner similar to that under study for high-level waste in future repositories, is modestly heat-producing. The gamma output is less than 4.5×10^3 rad/hr, which implies saturation of stored energy in the salt just as for high-level waste. The temperatures of salt in contact with remotely handled TRU waste will be less than those for high-level waste; annealing will be less important. Other comments concerning the local chemistry in the salt near high-level waste also apply to remotely handled TRU waste.

In summary, the temperature requirement for sudden release through annealing, 150°C, demands local energy inputs that are not available. The more credible mechanism for the release of stored energy is salt dissolution, an unlikely occurrence. If salt dissolution were to occur, its consequences near a canister of remotely handled TRU waste or spent fuel could be a local temperature rise, averaging a few degrees Celsius; hydrogen-gas production through radiolysis; and possible alteration of the chemical and mineral constituents of the material near the canister. For contact-handled TRU waste the energy is deposited mostly in the waste matrix. Whether this energy, less than 1 cal/g, is available on dissolution is a matter for study, but the consequences are expected to be negligible. No credible mechanical or thermal mechanism for the catastrophic release of stored energy from radiation damage has been identified.

9.5.3.6 Nuclear Criticality

The canisters to be emplaced in the repository will contain amounts of fissile material ranging from several grams in typical packages of contact-handled TRU waste to nearly 6 kilograms in each spent-fuel canister. The fissile material will not, however, form a critical mass, because it will be widely dispersed through other material that does not moderate and reflect neutrons adequately. Simple comparison of this mixture of material with assemblies known not to be critical has shown that emplacement configurations are not critical (Claiborne and Gera, 1974; Bingham and Barr, 1979).

To estimate criticality more quantitatively, it is possible to use techniques developed in the nuclear-weapons program for analyzing complex assemblies of fissile and nonfissile materials. D. R. Smith of the Los Alamos Scientific Laboratory has used these methods (Lathrop, 1965) to calculate the infinite multiplication factors that would characterize the wastes stored in contact-handled TRU-waste repositories. The infinite multiplication factor is a quantity describing the criticality of an assembly containing fissile material; it is the ratio of the number of fissions in one generation to the number of fissions in the preceding generation. If this ratio is less than unity, no self-sustaining chain of fissions can occur, even in an infinitely large assembly.

Using a criticality program called DTF IV, Smith has modeled the contact-handled TRU-waste problem by assuming drums loaded with various amounts of material in an infinite array. He has calculated that, for the multiplication factor to reach unity, the drums would have to contain amounts of plutonium far above the amounts now allowed by the U.S. Department of Transportation (Section 6.2.1). For example, a drum holding 140 kilograms of waste would have to contain over 5 kilograms of plutonium before the fissile material could form a critical mass; drums typically contain less than 0.01 kilogram of plutonium, and none are allowed to contain more than 0.2 kilogram.

Since spent-fuel assemblies contain much more fissile material than do contact-handled TRU-waste containers, a separate calculation has examined the criticality of the spent-fuel demonstration at the reference repository. Neutron-multiplication factors for infinite linear arrays of PWR fuel assemblies were calculated by J. T. Thomas of the Oak Ridge National Laboratory, using the KENO IV criticality program (Petrie and Cross, 1975). The calcula-

tions were based on new (unirradiated) fuel assemblies, which are more reactive than the spent-fuel assemblies to be received at the WIPP. Another conservative assumption was that the temperature of the salt storage matrix is 40°C; in actual spent-fuel storage the initial salt temperature would be much higher, and the reactivity of the system would be correspondingly lower.

At the areal power density, 30 kW/acre, specified for the WIPP spent-fuel storage demonstration, the centerline distance between adjacent fuel assemblies is 4.3 meters. Because neutronic coupling is weak between fuel assemblies that far apart, Thomas's calculations assumed a centerline distance of only 1.0 meter, corresponding to an areal power density of about 130 kW/acre. The calculation covered the five emplacement configurations listed in Table 9-50. The first of these describes spent fuel as emplaced, with salt between the canisters and nothing inside the canisters except the fuel assemblies. The next three configurations represent the aftermath of water intrusion; water has attacked the salt between canisters, has entered the void space inside the canisters, or has appeared in both places. The fifth configuration represents canisters with water inside and no moderating material outside; this extreme configuration examines the consequences of a dissolution process that removes all the salt from the repository and leaves the canisters behind. The five assumed configurations thus range from a conservative description of initial emplacement to a description of a highly unlikely event.

Table 9-50 displays the neutron-multiplication factor K for each of the assumed configurations. All of the factors are less than unity. None of the configurations show any possibility that the spent-fuel canisters will form a critical assembly.

Table 9-50. Neutron-Multiplication Factors K for Various Configurations of PWR Spent Fuel in the WIPP Reference Repository

Configuration (with 1-meter spacing)	K
1. Solid-salt spacing; normal canisters	0.1
2. Saturated-brine spacing; normal canisters	0.1
3. Solid-salt spacing; water-flooded canisters	0.6
4. Saturated-brine spacing; water-flooded canisters	0.57
5. Void spacing; water-flooded canisters	0.6

A manyfold reconcentration of fissile material would have to occur in the repository before a critical mass could form. Such reconcentration would require extensive dissolution of the salt and the waste; after dissolution, additional unlikely processes would have to act on the waste, selectively removing fissile nuclides from their surroundings and collecting them into a separate mass. The only natural processes that are known to have concentrated fissile material into a critical mass occurred in the Oklo phenomenon (IAEA, 1975; Cowan, 1976); these processes operated on a body of underground fissile material that was much more concentrated than the contents of the WIPP will be.

Furthermore, even if criticality could occur in a repository, it would tend to be self-limiting; because it would heat the solution in which the critical mass formed, it would give rise to faster neutrons, which are less effective in producing fissions. If a critical assembly were to form, its primary effects would be the production of hot brine and an altered fission-product inventory.

Further studies will, however, continue to investigate hypothetical scenarios (Bingham and Barr, 1979) describing the reconcentration of fissile material. If any of these scenarios appear to have an appreciable probability of occurring, additional calculations will study their effects; the mere formation of a critical mass does not necessarily have important consequences for the repository (Bingham and Barr, 1979). Calculations investigating criticality and its consequences will be completed during the next 2 years. In view, however, of the self-limiting behavior of a critical assembly and the reconcentration required to produce it, there is no expectation that nuclear criticality is a threat to the WIPP reference repository.

It is important to note that, even if the materials could form a critical assembly, they still could not explode. Although the terms "critical-mass formation" and "nuclear explosion" seem to be used interchangeably by the public, they represent entirely different concepts. For stored waste to become a nuclear bomb, it would not only have to form a critical mass but would also have to undergo extremely rapid compression to a very high density while simultaneously experiencing a flux of neutrons much greater than any sources in the mine will produce. No known mechanisms can compress underground nuclear waste to such densities in the short time (perhaps a fraction of a microsecond) required to make the fissile material explode. A nuclear explosion of the stored wastes is not a credible threat to the repository.

9.5.3.7 Thermal Effects on Aquifers

Section 9.5.2.1 presents the results of calculations showing that temperature increases in the aquifers near the repository will be of little consequence. Still under investigation, however, is the general problem of the effects on aquifers when heat-producing waste raises temperatures significantly.

Generalized shear-stress estimates for the aquifers near the repository (Maxwell, Wahi, and Dial, 1978) suggest a possibility of changes in flow characteristics as a result of the emplacement of hot waste. To assess possible mineral changes, the equation of state of the affected geologic-formation materials will be needed. Another complex problem, currently under investigation, is the possible fracturing of the water-bearing rocks. A further objective of the on-going programs is to evaluate the uncertainties introduced into stress calculations by uncertainty in the knowledge of thermomechanical properties of the WIPP geologic media and by the lack of homogeneity in these media. It is important, however, that the consequence analysis in Section 9.5.1 has shown no serious long-term effects from hypothetical fracturing more severe than the fracturing likely to be induced by the heat-producing wastes in the WIPP reference repository.

9.6 EFFECTS OF REMOVING THE TRU WASTE STORED AT IDAHO

9.6.1 Introduction: Current and Future Practices

About 75% of the pad-stored defense TRU waste in the United States is located at the Radioactive Waste Management Complex (RWMC) at the Idaho National Engineering Laboratory (INEL) (Table 2-2). Although the TRU waste stored at the several DOE sites varies in its characteristics, and the local effects of removal will vary, this discussion of the effects in Idaho is considered to be representative of effects at all storage sites for defense TRU waste. Supporting calculations for the results presented in this section can be found in a separate document (DOE, 1979).

9.6.1.1 Waste Characteristics and Current Management Methods

Since 1970, contact-handled TRU waste at the RWMC has been stored at the 56-acre Transuranic Storage Area (TSA), a controlled area surrounded by a security fence with an intrusion alarm system. The waste is stored on two asphalt pads, each approximately 150 by 700 feet in size.

Currently, the solid TRU waste to be stored on TSA pads is received from the Rocky Flats Plant and other DOE operations in government-owned ATMX rail cars or on commercial truck trailers. (The ATMX shipments are made under the authority of Special Permit 5948 issued by the Hazardous Materials Regulation Board of the U.S. Department of Transportation (DOT). This permit has been periodically renewed, and its current expiration date is May 1980. The shipping containers for the waste received by truck meet DOT Class B requirements. These shipments comply with DOT-assigned number USA 6400 or USA SP 6679, depending on the point of origin.) The waste is contained in 4 by 4 by 7-foot plywood boxes covered with fiberglass-reinforced polyester, 55-gallon steel drums with polyethylene liners, or 4 by 5 by 6-foot steel bins. (Some of the waste placed earlier on the TSA was stored in containers of nonstandard sizes.) The containers are intended to be retrievable, contamination-free, for at least 20 years. The drums are stacked vertically in layers, with a sheet of 1/2-inch plywood separating each layer. When a stack has reached a height of approximately 15 feet, a cover consisting of 5/8-inch plywood, nylon-reinforced polyvinyl sheeting, and 3 feet of soil is emplaced.

From 1970 (when TRU waste was first stored on the TSA) until 1972, the plywood boxes used as containers were not covered with fiberglass-reinforced polyester. Such boxes constituted approximately 25% of the boxes placed on the TSA through the end of 1977. Because boxes currently received are covered with polyester, it is estimated that, by 1985 (the approximate date at which retrieval might begin), this percentage will have been reduced to 15%. Similarly, until 1972, the steel drums placed on the TSA had no polyethylene liners. (The 90-mil polyethylene liners provide additional containment for the TRU waste and additional assurance of container integrity for the 20-year storage interval.) Such drums constituted about 44% of the drums on the TSA as of the end of 1977. Because drums currently received are lined, it is estimated that, by 1985, this percentage will have dropped to about 30%.

It is estimated that, by 1985, approximately 3 million cubic feet of TRU waste will be stored at the TSA. The analysis performed for this study did not include the effects of any TRU waste that might be sent to, or generated at, the INEL after 1985. The effects of any such post-1985 waste on INEL operations and impacts are addressed elsewhere (DOE, 1979).

More complete descriptions of the INEL, the RWMC, and the TRU waste stored on the TSA pads can be found in a document recently published by the DOE (1979).

9.6.1.2 Methods for Retrieving, Processing, and Shipping Waste

Several operations will be involved in removing the waste and shipping it to a Federal repository: retrieval, processing and packaging, and shipping. Several options were considered for each operation, and one option for each was evaluated in detail.

Three methods of retrieving waste containers were considered: (a) manual handling by operators; (b) handling by means of operator-controlled equipment; and (c) handling by means of remotely controlled equipment. The first method was not evaluated further because of unnecessary radiological exposure to the workers. The third method was not examined further because the preliminary indications of current studies are that no significant overall advantages accrue from remote-control handling.

Four confinement methods for waste retrieval were considered: (a) open-air retrieval (no confinement); (b) use of an inflatable fabric shield to protect against the weather; (c) use of a movable, solid-frame structure operating at ambient pressure; and (d) use of a movable, solid-frame structure operating at subatmospheric pressure. The fourth method was pursued because it is the only one of the four that provides positive control against the possible release of contamination.

Four processing options were considered: (a) ship as is; (b) repackage only; (c) compact, immobilize, and package; and (d) incinerate and package. Waste shipped to the repository will have to meet the repository acceptance criteria. The draft acceptance criteria of July 1977, used as a basis for selecting a processing method to be studied, effectively limit the waste to 20% by volume of combustibles and 10% by weight of gas-forming materials. Because approximately 25% by volume of the stored TRU waste is combustible, the waste would have to be incinerated to satisfy the draft criteria. An evaluation of incineration methods (FMC, 1977) has shown that only the product of slagging pyrolysis would satisfy all of the acceptance criteria without a separate immobilization step and without sorting and shredding the waste. The packaging for the slag product was assumed to be 55-gallon steel drums because of availability and past experience with this type of container.

Rail shipment of the waste was assumed because it is cheaper than shipment by truck. (Use of ATMX railcars was assumed for the purposes of this study. These may be replaced by the start of the retrieval campaign.)

Thus, the sequence of operations selected for study was (a) retrieval with operator-controlled equipment inside a movable, solid-frame structure at subatmospheric pressure; (b) processing by slagging pyrolysis, with the slag packaged in 55-gallon drums; and (c) shipment in ATMX railcars. These operations and their effects are briefly discussed in the following subsections. Detailed descriptions of the operations and of their effects may be found in a document recently published by the DOE (1979).

9.6.2 Retrieval

9.6.2.1 Retrieval Building and Operations

The retrieval building will be a mobile, single-walled structure. Subatmospheric pressure will be maintained inside to preclude the escape of contaminants. The ventilation system will include roughing filters and a bank of high-efficiency particulate air (HEPA) filters, for an estimated overall decontamination factor of 10^3.

The sequence of retrieval activities is shown in Figure 9-27. The building will be erected on an asphalt pad extending from a TSA pad. Most of the soil cover will be removed from the area to be covered by the building. After the building has been moved over this area, the remainder of the soil, the polyvinyl, and the plywood cover will be removed.

The retrieval equipment (forklift and front-end loader) will have environmentally protected cabs with self-contained breathing-air supplies. The breathing air will maintain a positive air pressure inside the cab to preclude in-leakage of possibly contaminated air. Preliminary calculations indicate that shielding of retrieval personnel will not be required; however, if necessary, removable shields will be mounted on the equipment.

The waste containers will be inventoried and examined to confirm their integrity. Any breached containers will be placed in a waste-transfer container and loaded into a transfer vehicle. Forklifts will remove the intact containers from the stacks and place them into the transfer vehicle. The waste will be transferred from the retrieval building to the processing plant in low-speed semitrailers pulled by a conventional tractor over committed roadways within the RWMC. The van bodies of the trailers will be designed to resist rupture in the event of an accident.

During loading or unloading, the van body will be mated and sealed to an airlock entrance, thereby forming an airtight extension of the airlock. Contamination of the exterior of the vehicle is not expected.

9.6.2.2 Environmental Effects of Retrieval

Radiological effects from retrieving the stored waste will be limited because it is intended that the stored TRU waste be fully contained at the time of retrieval. However, for scoping the effects of possible releases, it was assumed that 1% of the containers will have been breached before retrieval

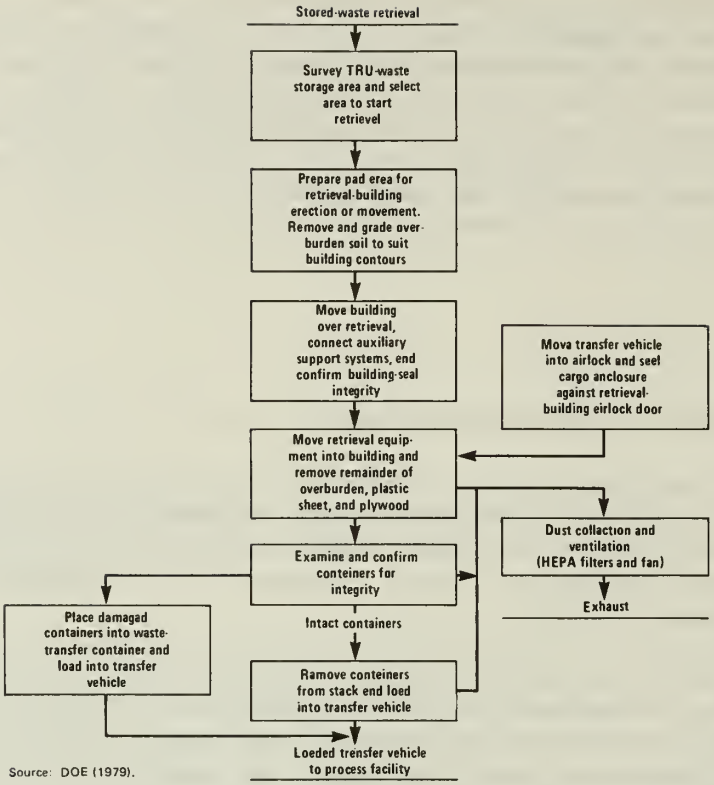

Figure 9-27. Block diagram for the retrieval of stored TRU waste.

begins and 0.1% of the radioactivity in each breached container will be released into the retrieval building, with 0.01% of the released radioactivity becoming resuspended. Table 9-51 shows the average release rates, maximum levels of soil contamination from releases, and the present radionuclide concentration in INEL soils from natural background radiation and atmospheric fallout due to weapons testing.

As shown in Table 9-51, present radionuclide concentrations in INEL soil are several orders of magnitude higher than those projected to result from retrieval operations.

The maximum annual radiation-dose commitments for any person not involved in the operation and for the population within 50 miles of the retrieval facility are compared in Table 9-52 with doses received from natural background radiation. The maximum individual dose commitment assumes the person resides at the point of maximum airborne concentrations throughout the year.

As stated at the beginning of Section 9.6, the assumptions and supporting data and details of dose, dose-commitment, and risk calculations summarized here and later are to be found in a separate document published by the DOE (1979).

As shown in Table 9-52, both individual and population dose commitments from routine releases during retrieval will be several orders of magnitude lower than doses received from natural background radiation.

Table 9-51. Comparison of Soil Contamination Resulting from Routine Releases During Retrieval Operations with Existing Natural and Fallout Concentrations of Radionuclides[a]

Nuclide	Average release rate from facility (pCi/sec)	Maximum cumulative concentrations in soil (nCi/m^2)	Present concentrations in INEL soil (natural and fallout contributions) (nCi/m^2)
Pu-238	2.2×10^{-4}	4.8×10^{-5}	0.15
Pu-239	1.8×10^{-4}	4.1×10^{-5}	(b)
Pu-240	4.3×10^{-5}	9.5×10^{-6}	(b)
Pu-241	8.2×10^{-4}	1.4×10^{-4}	(c)
Pu-242	1.0×10^{-9}	2.4×10^{-10}	(c)
Am-241	7.2×10^{-4}	1.6×10^{-4}	0.3
Cm-244	9.8×10^{-6}[d]	1.7×10^{-6}	(c)
U-233	7.8×10^{-6}[d]	1.8×10^{-6}	(c)

[a]Data from DOE (1979).
[b]The total of these two nuclides is 1.1 nCi/m^2.
[c]Not measured.
[d]This table contains nuclides (for contact-handled TRU waste) not listed in Appendix E. The appendix describes typical Rocky Flats waste. The waste stored at INEL, even though primarily Rocky Flats waste, also includes waste from other sources. The uranium-233 is from the Bettis Atomic Laboratory in Pennsylvania and the curium-244 is from the Savannah River Plant. The quantities of the additional nuclides are small and are only considered in the analysis of Sections 9.6 and 9.7.

Table 9-52. Comparison of Dose Commitments from Routine Releases During Retrieval Operations with Natural-Background-Radiation Doses

Organ or tissue	Maximally exposed person (mrem)[b]	Population within 50 miles (man-rem)[c]
Whole body	2.4×10^{-11}	2.9×10^{-10}
Lung	4.5×10^{-7}	4.1×10^{-6}
Bone	4.6×10^{-7}	4.2×10^{-6}
Liver	3.4×10^{-7}	3.1×10^{-6}
Kidney	1.6×10^{-7}	1.5×10^{-6}

[a]Data from DOE (1979).
[b]Annual whole-body dose from natural background radiation is 150 mrem.
[c]Annual whole-body dose to this population from natural background radiation is 2×10^4 man-rem.

The nonradiological effects of retrieval will be those associated with a commitment of manpower and the use of other resources. Neither the construction nor the operation of the retrieval facility will measurably increase the total particulate emissions at the INEL. The overall effect on land use will be to restore the area now used for waste storage within the RWMC to its once-vegetated state--a beneficial effect.

Resources used can be tabulated as follows (DOE, 1979):

Construction period, months	9
Average number of construction personnel	50
Construction man-months	450
Housing-unit requirements	38
Pieces of equipment	10
Diesel fuel used, gallons	54,000
Particulate emissions, pounds	5900
Operations period, years	10
Personnel	39
Estimated annual payroll	$624,000
Electricity use, kW-hr/yr	600,000

The resources used are not insignificant, but their use will not place any strain on either the local or the national economy. Other effects, such as water use and sanitary-waste disposal, will be in proportion to the employment levels.

9.6.2.3 Radiological Risk to the Public from Retrieval Operations

A number of potential accidents were considered in connection with retrieval, including (a) a fire in the retrieval building with an accompanying filter failure, (b) the dropping of a waste container during handling, and (c) the puncture or crushing of a container by retrieval equipment. For the dominant accidents, Table 9-53 summarizes the calculated dose and risk for the individual receiving maximum exposure and for the public within 50 miles. (Risk is defined here as the 50-year dose commitment multiplied by the annual probability of the accident.)

A number of abnormal events, generally related to natural disasters, could also affect the waste in the retrieval building. Examples are earthquakes, tornadoes, volcanic action (the RWMC lies at the edge of a volcanic rift zone), and aircraft impact. These abnormal events would not be a result of retrieval operations, because they could occur even if the waste were left as is; therefore, they are not discussed further here. They are taken up in Section 9.7 as events that may affect the stored waste if no TRU-waste repository is built and the waste is left at the INEL. Comparison with results given there shows that the radiological dose from such natural disasters could be about 100,000 times larger than that for the worst accident listed in Table 9-53.

Table 9-53. Summary of Dose Commitments and Risks from Accidents During the Retrieval of Stored TRU Waste[a]

Event	Maximally exposed person: 50-year dose commitment (rem) Whole body[b]	Bone	Lung	Risk (rem/yr) Whole body	Bone	Lung
Fire	6×10^{-7}	3×10^{-4}	4×10^{-4}	6×10^{-10}	3×10^{-7}	4×10^{-7}
Dropped container	7×10^{-12}	5×10^{-9}	7×10^{-9}	7×10^{-14}	5×10^{-11}	7×10^{-11}

Event	Population in 1985: 50-year dose commitment (man-rem) Whole body[c]	Bone	Lung	Risk (man-rem/yr) Whole body	Bone	Lung
Fire	8×10^{-4}	4×10^{-1}	8×10^{-1}	8×10^{-7}	4×10^{-4}	8×10^{-4}
Dropped container	1×10^{-8}	7×10^{-6}	1×10^{-5}	1×10^{-10}	7×10^{-8}	1×10^{-7}

[a]Data from DOE (1979).

[b]The 50-year whole-body dose commitment from natural background radiation is 7.5 rem.

[c]The 50-year population whole-body dose commitment from natural background radiation is 1×10^6 man-rem.

9.6.2.4 Hazards to Workers During Retrieval

Hazards to workers can be classified as radiological and nonradiological. The former are related to the radiological characteristics of the waste and consist of those associated with normal operations and those associated with accidental releases. The nonradiological hazards are those that could exist even if the waste were not contaminated with radionuclides (e.g., falls and electrical shocks). A number of measures will be taken to control these occupational hazards to within normally accepted levels.

The radiation levels to which workers are exposed will be monitored by health-physics personnel; radiation doses will be held to levels as low as practicable by following specified procedures. The daily and accumulated doses will be monitored.

To minimize the possibility of contamination, retrieval workers will work in dust-tight enclosures, will wear protective clothing, and will be provided with respiratory protection as needed. Workers will be surveyed frequently whenever the possibility of external contamination exists. Bioassays will be performed periodically.

In addition, continuous-air-sampling and radiation-monitoring instruments in the work areas will promptly detect and annunciate abnormal or accident conditions. Special procedures will be established for evacuating personnel, controlling the spread of contamination, and correcting accident conditions.

Preliminary calculations indicate that, during normal operating conditions, unshielded operators retrieving stored waste will receive radiation doses (an estimated maximum of 300 mrem/yr) that are well below the established limits for radiation workers (5000 mrem/yr). Operators have been placing waste into storage on the TSA at INEL for 7 years without having received exposures above radiation-worker limits.

Some of the worker doses resulting from accident conditions can be estimated by comparison with the public risk results in Section 9.6.2.3. The maximum individual doses given there can be used to estimate worker doses for accidents in which significant quantities of radionuclides would escape from the facility. Examples are such accidents as volcanic action, earthquakes, and airplane crashes.

Other accidents in which workers could receive significant doses while inside the facility were also examined. For example, accidental inhalation exposure could occur if a box were dropped and breached simultaneously with a failure of the worker's environmental cab. The airborne radioactivity was estimated to be 10^{-6} μCi/ml. For a breached box, an operator would receive a maximum permissible body burden in approximately 40 minutes. For a breached drum, the maximum permissible body burden would be received in 10 hours. The workers would be expected to evacuate the facility within minutes.

The number of nonradiological injuries that retrieval workers might incur was estimated by comparing the operations involved in retrieval with similar operations in other industries for which occupational injury rates are available. The results indicated an estimated eight nonradiological injuries during the retrieval campaign. One additional injury might be expected during the construction of the retrieval facility. In addition to these normal nonradiological hazards, special nonradiological hazards may be associated with the retrieval of the stored waste. The waste may contain pyrophoric materials and toxic chemicals.

9.6.2.5 Cost of Retrieval

The cost estimates presented in this section and in Section 9.7 include capital costs, operating and maintenance costs, and the cost of decontamination and decommissioning. The estimates are not considered budgetary cost estimates because they are based on a preconceptual design. Furthermore, most indirect capital costs (design, construction management, etc.) are not included. Uncertainties of as much as a factor of 2 are not unusual in this type of estimate, but this degree of accuracy is considered sufficient for the present study. The costs are based on constant 1978 dollars.

The estimated costs of retrieving the stored waste that will have been accumulated to 1985 are as follows (DOE, 1979):

Capital	$ 8,000,000
Operating and maintenance	16,000,000
Decontamination and decommissioning	1,000,000
Total	$25,000,000

9.6.3 Processing for Repository Acceptance

For purposes of this study it was assumed that a slagging-pyrolysis plant will be constructed near the TSA to chemically stabilize the waste, reduce its volume, and immobilize it. The slag product will be cast and packaged in a form that could be shipped to the repository.

9.6.3.1 Plant and Operations

A block flow diagram for slagging pyrolysis is shown in Figure 9-28. A slagging unit with a feed rate of about 41 tons per day of waste and makeup soil will be used. The building will be designed with three separate air zones, each equipped with its own ventilation system to maintain progressively lower pressures between the outside atmosphere and the innermost zone, which would include the waste-processing areas. All air removed by the ventilation systems will pass through appropriate HEPA filtration systems.

Retrieved waste will be transferred from the TSA to the receiving airlock of the processing plant. All operations in the plant, from waste entry through the airlock to final packaging, will be remotely controlled. After monitoring for contamination, incoming waste containers will be emptied. The waste will be spread on a conveyor belt and inspected for hazardous materials.

The waste will be blended to achieve some uniformity of the feed material. Makeup soil (1.5 pound per pound of waste) will be added to facilitate the formation of a glasslike slag of minimum leachability. Coal and wood bark will be added to the waste as supplementary fuel and to increase the porosity of the feed material. The molten slag will be poured into molds, cooled, and packaged into steel drums, which will be labeled and loaded into ATMX railcars for shipment to the repository.

An offgas-treatment system for the slagging incinerator will be employed to limit the releases of particulates, aerosols, and volatile compounds to levels complying with standards set by the DOE, the Environmental Protection Agency, and other government agencies.

9.6.3.2 Environmental Effects of Processing

The radiological impact from operating a slagging-pyrolysis plant will result from two sources of airborne radioactive effluents: (a) contamination generated when material is being prepared for slagging pyrolysis, and (b) offgas from the slagging-pyrolysis process. These streams will pass through HEPA filters and offgas-treatment systems before release, resulting in estimated decontamination factors of 10^6 and 10^8, respectively.

One consequence of the airborne effluents will be the gradual buildup of released radioactivity in the environment. Table 9-54 summarizes the average release rates, maximum levels of soil contamination, and the present radionuclide concentration in INEL soils from natural background radiation and atmospheric fallout. As shown in Table 9-54, the projected buildup of radionuclides in INEL soils from the slagging operation would exceed, in some

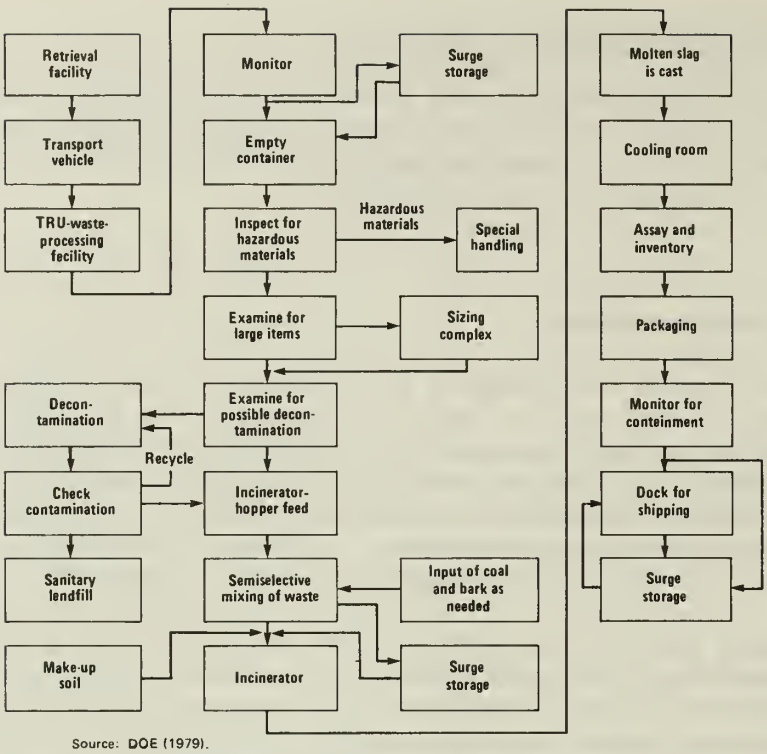

Figure 9-28. Block diagram for processing TRU waste by slagging pyrolysis.

Table 9-54. Comparison of Soil Contamination Resulting from Routine Releases During Slagging Pyrolysis with Existing Natural and Fallout Radionuclide Concentrations[a]

Nuclide	Average release rate from plant (pCi/sec)	Maximum cumulative concentration in soil (nCi/m^2)	Present concentrations in INEL soil (natural and fallout contributions (nCi/m^2)
Pu-238	1.1	0.38	0.15
Pu-239	0.85	0.32	(b)
Pu-240	0.21	0.077	(b)
Pu-241	3.9	1.1	(c)
Pu-242	5.0×10^{-6}	1.9×10^{-6}	(c)
Am-241	3.3	1.2	0.3
Cm-244	0.047	0.014	(c)
U-233	0.046	0.017	(c)

[a]Data from DOE (1979).
[b]The total of these two nuclides is 1.1 nCi/m^2.
[c]Not measured.

cases, the existing soil concentration resulting from natural and fallout radionuclides. The implications of these projections can best be understood in the context of the resulting radiation-dose commitments, discussed below.

The maximum radiation-dose commitments from airborne effluents annually for any individual and for the population within 50 miles of the slagging-pyrolysis plant are presented in Table 9-55.

As shown in Table 9-55, both individual and population annual dose commitments from slagging pyrolysis would be several orders of magnitude lower than doses presently received from natural background radiation.

Table 9-55. Comparison of Dose Commitments from Routine Releases During Slagging Pyrolysis with Background Doses[a]

Organ or tissue	Maximally exposed person (mrem)[b]	Population within 50 miles (man-rem)[c]
Whole body	1.9×10^{-7}	2.3×10^{-6}
Lung	3.5×10^{-3}	3.3×10^{-2}
Bone	3.6×10^{-3}	3.3×10^{-2}
Liver	2.7×10^{-3}	2.5×10^{-2}
Kidney	1.3×10^{-3}	1.2×10^{-2}

[a]Data from DOE (1979).
[b]Annual whole-body dose from natural background radiation is 150 mrem.
[c]Annual whole-body dose to this population from natural background radiation is 2×10^4 man-rem.

The nonradiological effects of slagging pyrolysis will be limited to those associated with a commitment of manpower and the use of other resources. A summary listing of the resources used is as follows (DOE, 1979):

Construction period, months	20
Average number of construction personnel	275
Construction man-months	5500
Housing unit requirements	200
Pieces of equipment used	30
Diesel fuel used, gallons	360,000
Particulate emissions, pounds	40,000
Operation period, years	10
Personnel	195
Estimated annual payroll	$3.3 million
Electricity use, kW-hr/yr	24 million
Coal used, tons/yr	4000
Bark used, tons/yr	6000
Particulate emissions, lb/yr	1.1

The increment in particulate emissions from the construction and operation of the slagging-pyrolysis plant would not be measurable, nor would it cause current limits to be exceeded.

The impact on local communities, particularly Idaho Falls, where two-thirds of the personnel are expected to live, would probably be felt most in the schools, which are already operating near capacity because of recent growth in the area.

The plant will occupy about 1.4 acres, totally within the current RWMC. Construction and operation will result in devegetation of this area. The area has, however, already been disturbed and is no longer in its natural state.

9.6.3.3 Radiological Risk to the Public from Waste Processing

In evaluating the dose commitments and risks from potential accidents associated with waste processing (slagging pyrolysis and packaging), accidents such as fires, spills of loose waste, and breaks in process lines were considered. The results are summarized in Table 9-56. For the three areas in the plant (waste preparation, slagging pyrolysis, and shipping), the dominant accident is a fire or an explosion, coupled with failure of the filters or other essential parts of the confinement.

The discussion of waste disruption due to natural disasters (e.g., earthquakes and volcanoes) in Section 9.6.2.3 applies to waste processing as well.

9.6.3.4 Hazards to Workers During Processing

The general discussion in Section 9.6.2.4 on the potential hazards to workers and preventive measures applies here as well. All operations in the slagging-pyrolysis plant will be remotely controlled, except for maintenance. Doses received by workers during normal operation are expected to be well below the allowable limits.

Maintenance workers performing manual retrieval will probably wear plastic bubble suits, supplied with breathing air from a central source. Under normal conditions and under most accident conditions, external and internal radiation exposures to these personnel will be well below radiation-worker limits. However, damage to the bubble suit could result in contamination of the worker. A maximum airborne contamination level of about 1×10^{-6} μCi/ml could exist. A worker would receive a maximum permissible body burden in such an atmosphere only if he remained in the cell for about 40 minutes, breathing contaminated air. Evacuation within a matter of minutes is expected. If the bubble-suit damage were caused by a pointed or jagged object, the worker's skin could also be punctured. Contamination could thereby be deposited beneath the skin. Any puncture injury under these conditions will receive special medical attention.

Workers could also be exposed to the consequences of the accidents discussed in Section 9.6.3.3, involving releases of radionuclides to the outside environment of the processing plant. The doses received would be expected to be similar to those listed for the maximally exposed individual.

Table 9-56. Summary of Dose Commitments and Risks from Accidents During Slagging Pyrolysis and Packaging of Stored TRU Waste[a]

Event[a]	Maximally exposed person						Population in 1985					
	50-year dose commitment (rem)			Risk (rem/yr)			50-year dose commitment (man-rem)			Risk (man-rem/yr)		
	Whole body	Bone	Lung	Whole body	Bone	Lung	Whole body	Bone	Lung	Whole body	Bone	Lung
WASTE-PREPARATION AREA												
Fire	1×10^{-8}	7×10^{-6}	1×10^{-5}	1×10^{-10}	7×10^{-8}	1×10^{-7}	2×10^{-5}	1×10^{-2}	2×10^{-2}	2×10^{-7}	1×10^{-4}	2×10^{-4}
Explosion with failed confinement	2×10^{-8}	1×10^{-5}	2×10^{-5}	2×10^{-11}	1×10^{-8}	2×10^{-8}	4×10^{-5}	2×10^{-2}	4×10^{-2}	4×10^{-8}	2×10^{-5}	4×10^{-5}
PYROLYSIS AREA												
Fire	1×10^{-10}	7×10^{-8}	1×10^{-7}	1×10^{-12}	7×10^{-10}	1×10^{-9}	2×10^{-7}	1×10^{-4}	2×10^{-4}	2×10^{-9}	1×10^{-6}	2×10^{-6}
Explosion	1×10^{-4}	7×10^{-2}	1×10^{-1}	1×10^{-9}	7×10^{-7}	1×10^{-6}	2×10^{-1}	1×10^{2}	2×10^{2}	2×10^{-6}	1×10^{-3}	2×10^{-3}
Tornado with failed off-gas duct	4×10^{-7}	2×10^{-4}	3×10^{-4}	2×10^{-13}	1×10^{-10}	2×10^{-10}	5×10^{-4}	3×10^{-1}	40	2×10^{-10}	1×10^{-7}	2×10^{-7}
SHIPPING AREA												
Fire	1×10^{-11}	7×10^{-9}	1×10^{-8}	1×10^{-13}	7×10^{-11}	1×10^{-10}	2×10^{-8}	1×10^{-5}	2×10^{-5}	2×10^{-10}	1×10^{-7}	2×10^{-7}
Tornado	1×10^{-7}	7×10^{-5}	1×10^{-4}	5×10^{-14}	3×10^{-11}	5×10^{-11}	2×10^{-4}	1×10^{-1}	2×10^{-1}	1×10^{-10}	5×10^{-8}	1×10^{-7}
Natural background radiation (1 year)	7.5						1×10^{6}					

[a]Data from DOE (1979).

The number of nonradiological injuries estimated to involve process workers during the campaign is 15. In addition, an estimated 14 injuries are expected to occur during plant construction.

9.6.3.5 Costs of Processing

The costs of processing the stored TRU waste that will have accumulated at the INEL by 1985 were estimated by the methods described in Section 9.6.2.5. The results are summarized below (DOE, 1979).

Capital	$128,000,000
Operation and maintenance	119,000,000
Decontamination and decommissioning	13,000,000
Total	$260,000,000

9.6.4 On-Site Transfer, Handling, and Load-out for Shipment to the Repository

9.6.4.1 Operations

The procedures for handling waste containers during retrieval are described briefly in Section 9.6.2.1, which also discusses the methods for transferring the containers from the retrieval building to the processing plant. The handling procedures to be followed in the processing plant are briefly discussed in Section 9.6.3.1.

9.6.4.2 Environmental Effects

Vehicular noise and emissions associated with on-site waste transfer will be both small and isolated. The number of personnel required for these activities will also be small. The RWMC already has its own rail siding, and extending it will not involve significant effort nor use additional acreage outside the RWMC.

No releases of radionuclides are expected during waste transfer from the retrieval building to the processing plant. Releases resulting from the handling of containers inside these facilities are included in the analyses of Sections 9.6.2.2 and 9.6.3.2.

9.6.4.3 Radiation Risk to the Public

The radiation-dose commitments and risks calculated for handling and transfer accidents inside the retrieval and processing facilities were covered in the analyses of Sections 9.6.2.3 and 9.6.3.3 (Tables 9-53 and 9-56, respectively). The radiation-dose commitments and risks to the public will be small in comparison with those from other accidents (e.g., fires) that could occur during retrieval and processing.

Table 9-57 summarizes accidents and incidents that have occurred since 1970 during the handling of TRU waste at the RWMC. Approximately 88,000 containers have been handled in that time. Only one of the events listed led to the release of contamination, and, in that case, no contamination was found on the workers.

Table 9-57. Accidents or Incidents in TRU Waste Handling at the RWMC Since 1970[a]

Date	Incident	Effects
12/14/72	Puncturing of barrel and liner from Rocky Flats. Barrel did not contain TRU waste.	No contamination release.
7/9/75	Solid-sewage-sludge drum generated internal pressure causing bulging of lid. Drums were repacked in overpack containers.	No contamination release.
1976	Partial drum penetration by forklift. No breach of inner liner.	No contamination release.
1/9/78	Drum penetration by forklift; a small portion of contents was spilled onto the cargo container floor.	Small amount of local contamination, which was immediately contained and the drum overpacked. There was no airborne activity. A thorough survey after recontainment found no residual contamination.

[a]Data from DOE (1979).

During transfer from the retrieval building to the processing plant, the waste material will be contained within at least two barriers. Although the transfer vehicle could become involved in an accident (for example, a rollover accident or a collision with another vehicle), the expected frequency of such accidents is very low. There will be few, if any, other vehicles on the committed roadway used by the transfer vehicle, and the speed of the vehicle will be limited by a governor. The vehicle will be designed for extra stability against rollover. The estimated dose commitment and risk from the accidents that might involve the transfer vehicle are given in Table 9-58, which also includes estimated dose commitment and risk associated with accidents that could occur during the on-site portion (about 7 miles) of the rail shipping route to the repository. Such accidents might include derailments, collisions, and fires.

Accidents or incidents that have occurred since 1970 during TRU-waste shipment from the waste generators to the RWMC are listed in Table 9-59. None of the cases cited resulted in a release of contaminants.

Table 9-58. Summary of Dose Commitments and Risks from Accidents During the Transfer of Stored TRU Waste from the Retrieval Area to the Processing Plant and During the On-Site Portion of the Shipment to the Repository

Accident	Maximally exposed person[a]					
	50-year dose commitment (rem)			Risk (rem/yr)		
	Whole body[b]	Bone	Lung	Whole body	Bone	Lung
Transfer accident	9×10^{-8}	3×10^{-5}	6×10^{-5}	9×10^{-14}	3×10^{-11}	6×10^{-11}
Transfer accident with fire	9×10^{-6}	3×10^{-3}	6×10^{-3}	3×10^{-12}	9×10^{-10}	2×10^{-9}
Accidents in on-site portion of shipment to repository	3×10^{-10}	1×10^{-7}	2×10^{-7}	5×10^{-19}	2×10^{-16}	4×10^{-16}

Accident	Population in 1985					
	50-year dose commitment (man-rem)			Risk (man-rem/yr)		
	Whole body[c]	Bone	Lung	Whole body	Bone	Lung
Transfer accident	1×10^{-4}	6×10^{-2}	1×10^{-1}	1×10^{-10}	6×10^{-8}	1×10^{-7}
Transfer accident with fire	1×10^{-2}	6	10	3×10^{-9}	2×10^{-6}	3×10^{-6}
Accidents in on-site portion of shipment to repository	4×10^{-7}	2×10^{-4}	4×10^{-4}	1×10^{-15}	4×10^{-13}	1×10^{-12}

[a]Data from DOE (1979).

[b]The 50-year whole-body dose commitment from natural background radiation is 7.5 rem.

[c]The 50-year whole-body population dose commitment from natural background radiation is 1×10^{6} man-rem.

Table 9-59. Accidents or Incidents[a] Since 1970 During Off-Site Shipments of Waste to the RWMC

Date	Location	Incident	Effects
3/25/70	Blackfoot, ID	Seal missing on a truck trailer	Load intact, no other problem
6/15/71	Unknown	Opened ATMX car, evidence of fire on piggyback trailer inside (charred wood, not known if there were signs of fire on containers themselves	No breach, no contamination release
8/7/73	Blackfoot, ID	Derailment during switching of ATMX car	No release, no apparent damage
3/31/76 9/21/76	Unknown	Opened ATMX car, found evidence of hard humping: some wooden blocking was broken and 4 to 5 waste containers were dented	No breach, no breakage

[a]Data from DOE (1979).
[b]All incidents reported to safety personnel; reports are on file at DOE Health and Safety in Idaho Falls.

9.6.4.4 Hazards to Workers

The hazards to workers during on-site waste transfer and handling have been included in the discussions of retrieval hazards and processing hazards. Approximately one-third of the projected nonradiological injuries during operations (Sections 9.6.2.4 and 9.6.3.4) will occur during transfer and handling. The preventive and protective measures against radiological hazards will be the same as those discussed in Section 9.6.2.4.

Under normal conditions, workers operating the transfer vehicles will be exposed to minimal hazards. Under accident conditions, the operators could be exposed to the small amounts of contamination that might escape from the vehicle. These exposures are expected to be smaller than exposures that could occur in other waste-management operations.

9.6.4.5 Cost

The costs of handling the containers, loading in, loading out, and transfer from the retrieval area to the processing plant are included in the costs of retrieval and processing (Sections 9.6.2.5 and 9.6.3.5). The costs involved will be only a few percent, at most, of the total cost of retrieval and processing.

9.6.5 Conclusions

The effects in Idaho of retrieving, processing, and shipping the stored TRU waste will be minimal. The largest radiological impacts from normal operations will be dose commitments of 3.6×10^{-6} rem (bone) and 1.9×10^{-10} rem (whole body) for the maximally exposed individual and 3.3×10^{-2} man-rem (bone) and 2.3×10^{-6} man-rem (whole body) for the surrounding population, per year of operation. From hypothetical accidents, the maximum dose commitments would be 1×10^{-1} rem (lung) and 1×10^{-4} rem (whole body) for the maximally exposed individual and 200 man-rem (lung) and 2×10^{-1} man-rem (whole body) for the surrounding population. The maximum radiological risks from hypothetical accidents would be 1×10^{-6} rem/yr (lung) and 1×10^{-9} rem/yr (whole body) for the maximally exposed individual and 2×10^{-3} man-rem/yr (lung) and 2×10^{-6} man-rem/yr (whole body) for the surrounding population. The radiological effects of all of these exposures will be far smaller than the corresponding effects from natural background radiation. Nonradiological effects will be limited to relatively minor commitments of manpower and other resources.

9.7 IMPACTS OF LEAVING TRU WASTE AT IDAHO

If no Federal TRU-waste repository away from the current storage locations becomes available, there will be three general alternatives for managing stored TRU waste. These alternatives are discussed in terms of the methods that might be used at the Idaho National Engineering Laboratory (INEL); they represent the methods that might be used at the other storage locations:

1. The waste could be left in place, as is.

2. Improved in-place confinement could be provided for the waste.

3. The waste could be retrieved, processed, and disposed of at another location at the INEL.

Only the TRU waste expected to be received at the INEL Radioactive Waste Management Complex (RWMC) by 1985 is included in the evaluations presented here. The effects of waste that might be received after 1985 are addressed, and supporting evaluations for the results are presented, elsewhere (DOE, 1979).

9.7.1 Leave the Waste in Place, as Is

Description of operations

In this alternative, the stored TRU waste would be left in place, as is. The cover of plywood, polyvinyl sheeting, and 3 feet of earth over the waste would be maintained (Section 9.6.1). The present environmental monitoring and sampling procedures at the RWMC would be continued for perhaps 100 years, with improved procedures incorporated as they are developed.

Environmental effects

In the near term (i.e., up to 100 years after the implementation of a waste-management alternative), the environmental effects of this alternative would be essentially the same as those measured to date for operations in the Transuranic Storage Area (TSA) at the INEL. Direct radiation from the covered waste would be near natural-background levels. Routine emissions would not be expected. The nonradiological effects normally associated with construction projects (e.g., excavation of soil, use of motor fuels, emissions from construction equipment, and socioeconomic impacts from an influx of workers) would not be present. Thus, the effects on the environment, in the near term, would be the smallest of any of the alternatives considered.

Long-term environmental effects of this alternative would be associated with the disruptions caused by natural disasters or human intervention.

Radiological risk to the public

Normal waste-management operations would not be a hazard to the public under this alternative. Rather, the risks of this alternative would be associated with waste disruption by natural disasters. Table 9-60 shows the results of dose-commitment evaluations for the most important events of this

Table 9-60. Summary of Dose Commitments for Leaving the Stored Waste in Place, as Is[a]

Disruptive event	Maximally exposed person 50-year dose commitment (rem) Whole body	Bone	Lung
Explosive volcano	1×10^{-2}	8	20
Earthquake	2×10^{-8}	2×10^{-5}	4×10^{-5}
Mackay Dam failure	3×10^{-7}	8×10^{-4}	2×10^{-3}
Volcanic lava flow[b,c]	3×10^{-2}	50	90
Intrusion			
Ingestion	8×10^{-5}	2	N/A[d]
Inhalation	3×10^{-3}	60	60
50-year background dose	7.5	--	--

Disruptive event	Population[e] 50-year dose commitment (man-rem) Whole body	Bone	Lung
Explosive volcano	20	4×10^{4}	8×10^{4}
Earthquake	7×10^{-5}	1×10^{-1}	2×10^{-1}
Mackay Dam failure	1×10^{-3}	3	7
Volcanic lava flow[b,c]	1×10^{2}	2×10^{5}	4×10^{5}
Intrusion			
Ingestion	8×10^{-4}	20	N/A
Inhalation	3×10^{-2}	500	500
50-year background dose, 1985	1×10^{6}	--	--

[a]Data from DOE (1979).

[b]Overburden is assumed to resist lava flow as long as maintenance is continued. Release is assumed to occur 100 years after implementation, when maintenance has been discontinued.

[c]The dose-commitment calculations for this scenario are subject to large uncertainties and are undergoing further evaluation.

[d]N/A = not applicable.

[e]Population = 130,000, except for intrusion, where it is 10.

type. The evaluations were based on hypothetical releases occurring in the year 2085. (Risks were not evaluated because of the great uncertainties in estimating the probabilities of disruptive events many years in the future.)

One of the largest dose commitments would result from an explosive volcanic eruption up through the waste. The RWMC lies at the edge of the Arco Volcanic Rift Zone, which has been active for the last 400,000 years and is likely to be the site of future volcanic action (Kuntz, 1978). In an explosive eruption molten lava encounters groundwater at a relatively shallow depth beneath the surface of the earth; a small but significant number of eruptions in the eastern Snake River plain have been of this type in the past. A fraction of the waste could thereby become airborne and be carried off the site. This event is of very low probability, estimated to be about 4×10^{-9} per year.

The largest whole-body dose commitment would be the result of lava flow over the RWMC. The key difference between volcanic flow over the RWMC and the explosive eruption beneath the RWMC is that the former involves a volcanic eruption some distance away from the RWMC, with resulting lava flow over the RWMC. The waste could be disrupted, and a fraction could become airborne and be carried off the site. The lava-flow scenario is the more probable of these two scenarios, because eruptions originating in a larger area could deliver flows to the RWMC. As long as the cover over the waste is maintained, the effects would probably be minimal. However, if the waste were left in place indefinitely after maintenance operations cease, the cover would erode away, and the waste would be directly affected by the effects of lava flow. The thermal and mechanical effects of the flow could lead to releases of radionuclides estimated to be as large as 4200 Ci. The relative severities of the two scenarios for volcanic action are the subject of continuing studies. The results presented here are based on conservative assumptions and may overestimate greatly the quantity of radionuclides that would be released.

Another important scenario in Table 9-60 is future intrusion by small groups of people onto the waste site after institutional controls have lapsed. The individuals involved are assumed to live at the waste site, plow the land, eat food raised there, and dig into the waste looking for artifacts or construction materials.

Flooding of the RWMC could result from failure of the Mackay Dam, which is about 42 miles upstream on the Big Lost River. The dam could fail because of faulty design or construction, degradation, or seismic activity. This disruptive event is also listed in Table 9-60.

Cost

The estimated cost of continuing the present program of maintenance and surveillance for the TSA is $600,000 annually. (The number of years for which maintenance and surveillance would be continued cannot be projected with confidence.) Upgrading the program could increase this cost. In addition, capital costs for periodic replacement of some equipment items would be less than one-tenth of the operations cost.

9.7.2 Improve In-Place Confinement for Stored Waste

Description of operations

This alternative considers means of providing additional in-place protection for the waste. Protection would be provided against penetration of water and intrusion of animals and plant roots. This discussion covers two approaches for constructing confinement barriers for the waste (a barrier over the top and sides; and top, side, and bottom barriers) and one immobilization approach.

In the top-and-side-barrier approach, an additional 10-foot cover of compacted clay and a 3-foot cover of basalt riprap would be built up over the existing mounds on the TSA pads.

In the top-side-and-bottom-barrier approach, increased isolation would be provided by pressure-grout sealing of the sediments beneath the asphalt pad. Downward migration of the waste would be minimized for as long as the grout remained intact. Assurance cannot be given, however, that the grout would remain intact for the thousands of years required for the radionuclides to decay to background levels.

In the immobilization approach, the waste would be immobilized in place by injecting grout into the waste and into the sediments beneath the pad. The waste would thereby be encased in a massive, impermeable block of grout. The grout would not penetrate sound waste containers, which would be surrounded by the grout. This immobilization method would make any future retrieval extremely difficult.

For all of these methods of improved confinement, maintenance and surveillance would be continued and expanded as necessary, for perhaps 100 years, with improved procedures incorporated as they are developed.

Environmental effects

Under normal operational conditions, there would be no near-term radiological emissions from any of the three improved-confinement methods. Therefore, there would be no dose commitments to the public from this source. Direct radiation from the stored waste would be reduced by the shielding of the mound over the waste, and radiation exposures at the surface of the mound would be expected to be near background levels. Long-term environmental effects would be associated with the disruptive events considered in the risk analysis below.

Nonradiological effects would be those resulting from use of materials, energy, and labor. For example, it is estimated that 30,000 cubic yards of clay and 12,000 cubic yards of basalt riprap would be required for the additional protective cover over the waste. An estimated 1000 cubic yards of grout and 13,000 cubic yards of concrete would be required for grouting beneath the waste. The immobilization approach would require an estimated 34,000 cubic yards of grout. The waste-management area is already disturbed, so there would be no additional loss of habitat or use of lands. A possible habitat loss might be expected at playas where clay would be extracted to construct the waste overburden. This impact would be minor.

Radiological risk to the public

For the three confinement approaches discussed, the risk associated with the confinement operations themselves would be essentially zero. Only in the immobilization operation, in which grout pipes would be forced through the clay cover and the pad, can a release scenario associated with operations be envisioned. During insertion and withdrawal, the grout pipes would be provided with external containment to prevent the spread of contamination.

The hazards from waste-management operations would be much smaller than those from disruption of the waste by causes such as volcanoes or future intrusion on the waste site. The dose commitments for such scenarios (assuming they occur in the year 2085) are summarized in Tables 9-61, 9-62, and 9-63. These dose commitments are similar to the corresponding dose commitments discussed in Section 9.7.1.

Table 9-61. Summary of Dose Commitments from Disruptive Events for Approach with Top and Side Barrier Added[a]

Disruptive event	Maximally exposed person 50-year dose commitment (rem)		
	Whole body	Bone	Lung
Explosive volcano	1×10^{-2}	8	20
Earthquake	2×10^{-8}	2×10^{-5}	4×10^{-5}
Mackay Dam failure	3×10^{-7}	8×10^{-4}	2×10^{-3}
Volcanic lava flow[b,c]	3×10^{-2}	50	90
Intrusion			
Ingestion	8×10^{-5}	2	N/A[d]
Inhalation	3×10^{-3}	60	60
50-year background dose	7.5	--	--

Disruptive event	Population 50-year dose commitment (man-rem)		
	Whole body	Bone	Lung
Explosive volcano	20	4×10^{4}	8×10^{4}
Earthquake	7×10^{-5}	1×10^{-1}	2×10^{-1}
Mackay Dam failure	1×10^{-3}	3	7
Volcanic lava flow[b,c]	100	2×10^{5}	4×10^{5}
Intrusion			
Ingestion	8×10^{-4}	20	N/A
Inhalation	2×10^{-2}	500	500
50-year background dose	1×10^{6}	--	--

[a]Data from DOE (1979).

[b]Overburden is assumed to resist lava flow as long as maintenance is continued. Release is assumed to occur 100 years after implementation, when maintenance has been discontinued.

[c]The dose-commitment calculations for this scenario are subject to large uncertainties and are undergoing further evaluation.

[d]N/A = Not applicable.

Table 9-62. Summary of Dose Commitments from Disruptive Events for Approach with Top, Side, and Bottom Barriers Added[a]

Disruptive event	Maximally exposed person 50-year dose commitment (rem)		
	Whole body	Bone	Lung
Explosive volcano	1×10^{-2}	8	20
Earthquake	2×10^{-8}	2×10^{-5}	4×10^{-5}
Mackay Dam failure	3×10^{-7}	8×10^{-4}	2×10^{-3}
Volcanic lava flow[b,c]	3×10^{-2}	50	90
Intrusion			
Ingestion	8×10^{-5}	2	N/A[d]
Inhalation	3×10^{-3}	60	60
50-year background dose	7.5	--	--

Disruptive event	Population 50-year dose commitment (man-rem)		
	Whole body	Bone	Lung
Explosive volcano	20	4×10^{4}	8×10^{4}
Earthquake	7×10^{-5}	1×10^{-1}	2×10^{-1}
Mackay Dam failure	1×10^{-3}	3	7
Volcanic lava flow[b,c]	100	2×10^{5}	4×10^{5}
Intrusion			
Ingestion	8×10^{-4}	20	N/A
Inhalation	3×10^{-2}	500	500
50-year background dose	1×10^{6}	--	--

[a]Data from DOE (1979).

[b]Overburden is assumed to resist lava flow as long as maintenance is continued. Release is assumed to occur 100 years after implementation, when maintenance has been discontinued.

[c]The dose-commitment calculations for this scenario are subject to large uncertainties and are undergoing further evaluation.

[d]N/A = Not applicable.

Table 9-63. Summary of Dose Commitments from Disruptive Events for Approach with In-Place Immobilization of Waste[a]

Disruptive event	Maximally exposed person 50-year dose commitment (rem)		
	Whole body	Bone	Lung
Explosive volcano	1×10^{-4}	8×10^{-2}	2×10^{-1}
Earthquake	2×10^{-10}	2×10^{-7}	4×10^{-7}
Mackay Dam failure	3×10^{-10}	8×10^{-7}	2×10^{-6}
Volcanic lava flow[b,c]	3×10^{-4}	5×10^{-1}	9×10^{-1}
Intrusion			
Ingestion	8×10^{-7}	2×10^{-2}	N/A[d]
Inhalation	3×10^{-5}	6×10^{-1}	6×10^{-1}
50-year background dose	7.5	--	--

Disruptive event	Population 50-year dose commitment (man-rem)		
	Whole body	Bone	Lung
Explosive volcano	2×10^{-1}	400	800
Earthquake	7×10^{-7}	1×10^{-3}	2×10^{-3}
Mackay Dam failure	1×10^{-6}	3×10^{-3}	7×10^{-3}
Volcanic lava flow[b,c]	1	2×10^{3}	4×10^{3}
Intrusion			
Ingestion	8×10^{-6}	2×10^{-1}	N/A
Inhalation	3×10^{-4}	5	5
50-year background dose	1×10^{6}	--	--

[a]Data from DOE (1979).

[b]Overburden is assumed to resist lava flow as long as maintenance is continued. Release is assumed to occur 100 years after implementation, when maintenance has been discontinued.

[c]The dose-commitment calculations for this scenario are subject to large uncertainties and are undergoing further evaluation.

[d]N/A = Not applicable.

The ability of improved confinement to resist violent, disruptive events is difficult to assess. This ability would undoubtedly decrease as the engineered barriers deteriorate. A modest credit, ranging in value from a factor of 1 to a factor of 1000, has been taken here for the beneficial effects of the barriers in reducing the release quantities.

The dominant events, in terms of dose commitment, are those related to volcanic action and future intrusion.

Cost

The estimated costs for improving the confinement of TRU waste stored on the TSA are summarized below. The number of years for which maintenance and surveillance would be continued cannot be projected with confidence.

Estimated Cost of Improving Confinement (Millions of Dollars)*

Method	Capital	Annual operations and maintenance
Top and side barrier	1.0	0.6
Top, side, and bottom barriers	2.9	0.6
Immobilization	11.3	0.6

*Data from DOE (1979).

9.7.3 Retrieve, Process, and Dispose at the INEL

In this alternative, the stored TRU waste would be retrieved from its present location, processed, and shipped to a disposal facility elsewhere at the INEL. The retrieval and processing of the stored waste would begin in 1985 or as soon thereafter as practicable.

Description of facilities and operations

Retrieval. The waste would be retrieved as described in Section 9.6.2.

Processing. The constraint of making the waste product comply with the repository acceptance criteria would not necessarily apply in this alternative. Therefore, three possible methods were analyzed for processing the stored waste: (1) incineration by slagging pyrolysis, followed by packaging; (2) compaction, immobilization, and packaging; and (3) repackaging only.

Slagging pyrolysis is described in Section 9.6.3.

In the second processing method the waste would be compacted within fiberboard containers. The containers would be cast in concrete blocks, thus providing both immobilization and packaging. After the concrete had cured, the blocks would be monitored for contamination, decontaminated if necessary, and loaded onto a truck for shipment to the disposal location. A block flow diagram of the process is shown in Figure 9-29.

In the third processing method the waste would be reduced in size, if necessary, and then placed in new 55-gallon steel drums. A block flow diagram of the process is shown in Figure 9-30.

On-site shipment. On-site shipment of processed waste would be by semitrailers pulled by standard truck tractors.

The cast slag from slagging pyrolysis would be shipped in DOT-17C 55-gallon drums. Each drum would weigh about 1360 pounds.

The compacted and immobilized waste would be contained in 30-inch-diameter, 40-inch-long cylinders, four of which would be within a 63-inch-square, 43-inch-tall block of concrete. Each block would weigh about 8700 pounds.

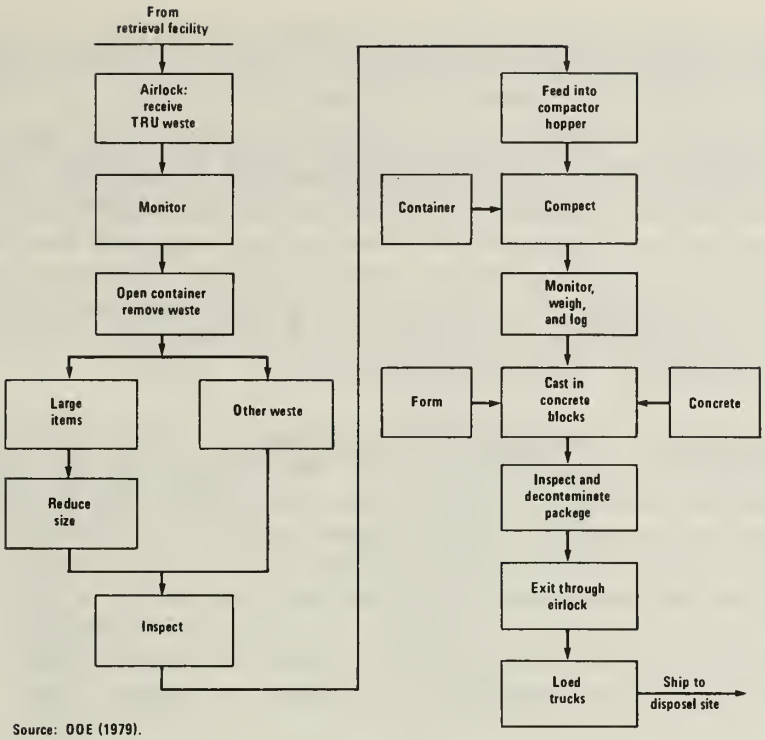

Figure 9-29. Block diagram for compaction, immobilization, and packaging of stored waste.

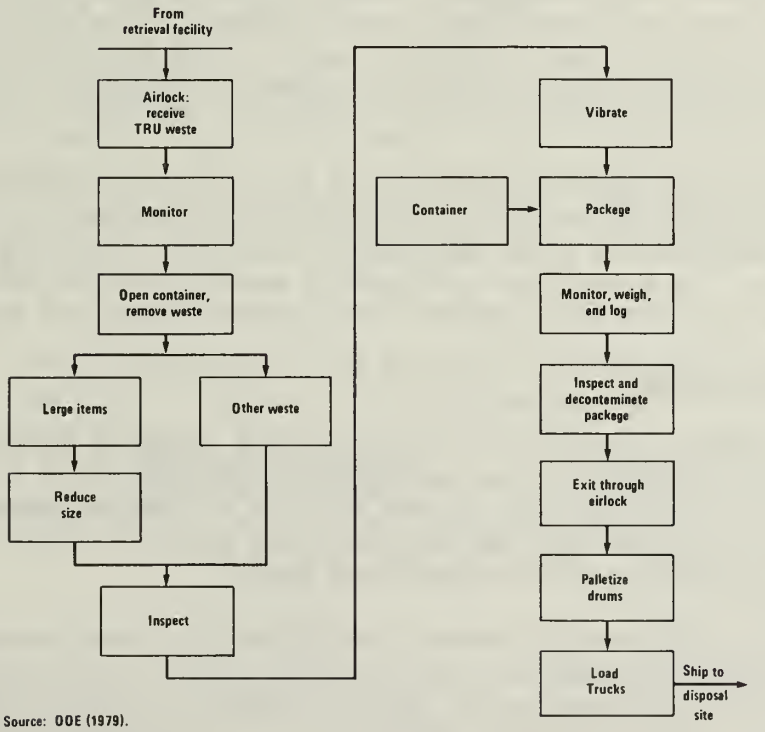

Figure 9-30. Block diagram of the repackaging-only processing.

The packaged waste would be shipped in DOT-17C drums. Each drum would weigh about 260 pounds.

On-site disposal. Two on-site disposal methods were analyzed; waste processed by any of the three methods discussed previously could be disposed of by either of these. The first method involves engineered shallow land disposal in lacustrine sediments at the central area of the INEL known as Site 14. This area has the deepest known surface sediments at the INEL. The second method is disposal of the waste in an aboveground concrete structure near the RWMC. Both disposal methods would be designed to allow retrieval of the waste, if necessary, during an observation period.

Engineered shallow land disposal at Site 14. The facility would consist of underground concrete structures in a rectangular array. Each structure would be buried so that its top would be well below the original ground surface. Each structure would contain rooms running the length of the structure and would have a high ratio of solid material to void, obtained by the use of massive interlocking concrete blocks and by the use of a thick layer of natural material (clay and basalt riprap) to protect the concrete from the environment. Two hypothetical designs were used in the analysis, one with less massive construction than the other in order to reduce cost.

Disposal in engineered surface facility near the RWMC. The location studied for the engineered surface-disposal facility is in the southeastern corner of the RWMC extending outside and to the south of the present fence. The surface soil in this area is typically 15 feet thick above a layer of basalt approximately 100 feet thick.

The engineered surface-disposal facility would consist of elongated, earth-covered, concrete structures, each resting on the basalt base. Including the cover material, each structure would stand considerably above ground level. Each structure would contain a number of disposal rooms extending its full length.

The structure would be massive, with the intention of providing long-term containment of the waste. It would have a high ratio of solid material (reinforced concrete) to void, obtained by the use of massive interlocking concrete blocks. A thick layer of natural material (clay and basalt riprap) on top of the concrete would protect the concrete from the environment.

Environmental effects

The environmental effects of retrieval and slagging pyrolysis are given in Section 9.6. The effects of constructing and operating a compaction, immobilization, and packaging process or from a repackaging-only process are described below. Since the two processes are similar, their releases and environmental impacts would be about the same.

Radioactive airborne effluents from either of these processes would result in a gradual buildup of radionuclides in the environment. Table 9-64 summarizes average release rates, maximum levels of soil contamination from these releases, and the present concentration of radionuclides in INEL soils from natural sources of radioactivity and from fallout. The projected buildup of radionuclides in INEL soils would be less than this existing soil concentration.

The maximum annual radiation-dose commitments from airborne effluents for any individual and for the population within 50 miles of the facility are presented in Table 9-65. Natural background doses in eastern Idaho are also presented. Both individual and population annual dose commitments from compaction and immobilization and from repackaging would be several orders of magnitude lower than doses presently received from natural background radiation.

Table 9-64. Radionuclide Contamination in INEL Soil[a]

Nuclide	Average release rate from facility (pCi/sec)	Maximum cumulative concentration in soil[b] (nCi/m^2)	Present concentration in INEL soil[c] (nCi/m^2)
Pu-238	0.15	0.053	0.15
Pu-239	0.12	0.044	([d])
Pu-240	0.028	0.010	([d])
Pu-241	0.53	0.16	([e])
Pu-242	6.9×10^{-7}	2.6×10^{-7}	([e])
Am-241	0.47	0.17	0.3
Cm-244	[f]6.5×10^{-3}	[f]1.9×10^{-3}	([e])
U-233	[f]5.2×10^{-3}	[f]1.9×10^{-3}	([e])

[a]Data from DOE (1979).
[b]From compaction and immobilization or from repackaging.
[c]From fallout and naturally occurring radionuclides.
[d]The total of these two nuclides is 1.1 nCi/m^2.
[e]Not measured.
[f]This table contains nuclides (for contact-handled TRU waste) not listed in Appendix E, which describes typical Rocky Flats waste. The waste stored at INEL, even though primarily Rocky Flats waste, also includes waste from other sources. The uranium-233 is from the Bettis Atomic Laboratory in Pennsylvania, and the curium-244 is from the Savannah River Plant. The quantities of the additional nuclides are small and are considered only in the analysis of Sections 9.6 and 9.7.

Table 9-65. Dose Commitments from Routine Releases from Compaction and Immobilization or from Repackaging[a]

Organ or Tissue	Maximally exposed person (mrem)[b]	Population within 50 miles (man-rem)[c]
Whole body	2.6×10^{-8}	3.2×10^{-7}
Lung	4.9×10^{-4}	4.5×10^{-3}
Bone	5.0×10^{-4}	4.6×10^{-3}
Liver	3.7×10^{-4}	3.4×10^{-3}
Kidney	1.8×10^{-4}	1.7×10^{-3}

[a]Data from DOE (1979).
[b]Annual whole-body dose from natural background radiation is 150 mrem.
[c]Annual whole-body dose to this population from natural background radiation is 2×10^4 man-rem in 1985.

The nonradiological effects of compaction and immobilization and of repackaging would be limited to those associated with a commitment of manpower and the use of other resources. A summary listing of the resources used is as follows (DOE, 1979):

	Compaction and immobilization	Repackaging only
Construction period, months	20	18
Average number of construction personnel	250	200
Construction man-months	5,000	3,600
Housing unit requirements	188	150
Pieces of equipment used	25	20
Diesel fuel used, gallons	300,000	220,000
Particulate emissions, pounds	33,000	24,000
Operations period, years	10	10
Personnel	50	40
Estimated annual payroll	$825,000	$640,000
Electricity usage, kW-hr/yr	6×10^6	3×10^6

The increment in particulate emissions from the construction and operation of these facilities would not be measurable or cause current limits to be exceeded.

The areas of the two facilities would be about 1.8 and 1.0 acres, entirely within the current boundaries of the RWMC. The construction and operation of either facility would result in devegetation of the corresponding area. However, the area has already been disturbed and is no longer in its natural state.

The shipment and disposal of waste at the INEL disposal locations would not result in significant radiological effects, at least in the near term (up to 100 years). The waste would be packaged to prevent the release of contamination during normal handling and shipping. Small radiation exposures would occur to the work force from direct radiation. Physical controls and administrative procedures would be implemented to keep radiation doses to workers as low as practicable and within DOE standards (ERDAM-0524). Present experience with the handling of TRU waste indicates maximum doses on the order of 400-500 mrem/yr for individuals directly involved in the operations. There would be no exposure to the general population from normal operations because the waste would be shipped on committed roadways.

After the waste has been put in the disposal facility and the facility closed, long-term environmental effects of disposal would be associated principally with disruption of the waste by natural disasters.

Nonradiological impacts would result from the use of land, energy, resources, and labor. These impacts are presented in Table 9-66 for the four disposal locations, including the less massive variation of engineered shallow

Table 9-66. Nonradiological Impacts of Disposal[a]

Disposal method and location	Construction					Operations	
	Man-months[b]	Particulate emissions[b] (10^3 lb)	Diesel fuel[b] (10^3 gal)	Land[b,c] (acres)	Concrete[c] (10^3 yd^3)	Jobs[c]	Electricity[c] (10^6 kW-hr/yr)
Engineered surface disposal near the RWMC	250	8	70	33-94	360-1100	19-30	0.10 - 0.17
Engineered shallow land disposal at Site 14	390	10	90	230-410	430-1200	17-28	0.13 - 0.26
Less massive construction than above	290	8	80	170-230	14-41	8-19	0.13 - 0.26

[a]Data from DOE (1979).

[b]Includes committed roadway to Site 14.

[c]Ranges of values reflect the different output volumes of waste from the three processing methods studied. Highest values are for the repackage-only approach; lowest values are for compaction and immobilization and/or slagging pyrolysis.

land disposal. Implementation of this variation would greatly reduce the amount of concrete required, as shown in the table.

Construction of the roadways would remove some sagebrush habitat. Use of Site 14 would cause loss of some crested wheatgrass (introduced to increase the grazing area on the INEL). Both of these effects would be minor.

Radiological risks to the public

The radiological risks associated with retrieval and with slagging pyrolysis are discussed in Sections 9.6.2.3 and 9.6.3.3, respectively. The risks associated with processing by compaction and immobilization or by repackaging only would be within about one order of magnitude of those for slagging pyrolysis.

For each disposal method, the risk to the public during waste shipment and during the operational phase would be at least a hundred times smaller than that associated with processing the waste.

The radiological dose commitments to the public from the dominant accidents associated with the post-closure phase of waste disposal on the INEL are summarized in Table 9-67. For purposes of simplifying this presentation, the evaluations were based on hypothetical releases of radionuclides occurring in the year 2085. Longer-term evaluations have been performed (DOE, 1979), which show consequences of releases as a function of the time at which releases occur. Risks were not evaluated because of the uncertainties in estimating probabilities of disruptive events thousands of years in the future.

Table 9-67. Summary of Doses for Waste Disposal at the INEL[a,b]

Organ	Maximally exposed person, 50-year dose commitment (rem)	1985 Population, 50-year dose commitment (man-rem)
Whole body	1×10^{-4}	2×10^{-1}
Bone	8×10^{-2}	4×10^{2}
Lung	2×10^{-1}	8×10^{2}
50-year whole-body dose from natural background	7.5	1×10^{6}

[a]Data from DOE (1979).

[b]All values are for waste processed by repackaging only, which delivers the worst accident dose, and for either engineered surface disposal or engineered shallow land disposal.

The dominant event following disposal is volcanic action, either an eruption up through the waste or lava flow over it from a nearby eruption. A fraction of the waste could thereby become airborne and be carried off the site.

All the other evaluated scenarios were found to produce lower doses. Flooding is among these. The RWMC could be flooded by high water in the Big Lost River or by failure of the Mackay dam. Such water would pond on the INEL, where most of it would evaporate. To reach the Snake River Plain Aquifer, water would have to percolate downward through 580 feet of sediments and basalt. Flow in the aquifer is at the rate of 4 to 20 feet per day. Sorption would slow the transport of TRU nuclides. Peak concentrations would arrive at the INEL boundary (3 miles) at about 40,000 years. At the nearest point of potential use of groundwater by a sizeable population (the Hagerman-Twin Falls area along the Snake River), the peak would be delayed for about a million years. Dispersion and decay would cause resultant concentrations to be very low. Indeed, the analysis indicates a greater, but still minor, hazard from the resuspension of TRU nuclides left on the surface after the evaporation of ponded water (DOE, 1979).

No overwhelming differences in the long term level of safety were identified among the disposal methods. Although the engineered confinement structures were assumed to become completely degraded after many thousands of years, the predicted worst-case radiological exposures from hypothetical releases would not cause any near-term fatalities.

Radiological doses to workers

Those subalternatives that leave INEL waste on the present storage pads at the RWMC do not involve radiation exposure of workers other than that associated with maintenance and surveillance.

Subalternatives in which the waste is removed from the pads, processed, and disposed of on the INEL do involve some exposure of workers. These exposures are estimated to be no more than 400 mrem/yr for any individual, well below the present occupational limit of 5000 mrem/yr (DOE, 1979).

Cost

The estimated costs of retrieval and of processing for each of the three alternative methods evaluated are given below.

Estimated Costs of Retrieval and Processing (Millions of Dollars)[a]

Operation	Capital	Total O&M[b]	D&D[c]	Total
Retrieval	8	16	1	25
Slagging pyrolysis and packaging	128	119	13	260
Compaction, immobilization, and packaging	73	38	7	118
Repackaging only	56	51	6	113

[a]Data from DOE (1979).
[b]Operations and maintenance.
[c]Decontamination and decommissioning.

The estimated costs for on-site shipment and disposal are summarized in Table 9-68. For each disposal method, the costs are given for managing the waste form resulting from the three processing methods discussed. The estimated cost of the less massive version of engineered shallow-land disposal is less than that of the other version by a factor of about 2 to 4; the difference is due principally to the smaller quantity of concrete required.

9.7.4 Conclusions

The result of having no Federal TRU-waste repository would be that the TRU waste stored in Idaho (or other locations) could be (1) left in place as is; (2) left in place with improved confinement being provided; or (3) retrieved, processed, and disposed of at the INEL.

No normal operational releases of radioactivity would be associated with the leave-in-place alternative or the improved-confinement alternative. In the short term (i.e., up to about 100 years), the alternative with retrieval, processing, and disposal at the INEL would result in a greater radiological impact than the two other alternatives. The largest radiological impact would result from normal operational releases from the slagging-pyrolysis process.

Table 9-68. Estimated Costs of On-Site Disposal for Stored Waste (Millions of Dollars)[a]

Disposal method	Shipping	Capital	Total O&M[b]	D&D[c]	Total
Engineered shallow land					
SP[d]	0.5	159	68	0.4	228
CPT[e]	0.7	130	67	0.4	198
PKG[f]	0.5	356	72	0.5	429
Less massive variation of engineered shallow land					
SP	0.5	19	64	0.4	84
CPT	0.7	21	63	0.4	85
PKG	0.5	43	68	0.5	112
Engineered surface facility					
SP	0.4	91	69	0.06	160
CPT	0.5	95	68	0.06	164
PKG	0.4	265	73	0.09	338

[a]Data from DOE (1979).

[b]For each entry in this column, $60 million of the operations-and-maintenance (O&M) costs stemmed from 100 years of maintenance and surveillance.

[c]Includes only costs associated with decontamination and decommissioning (D&D) of service facilities such as maintenance facilities. No D&D would take place for the disposal facilities themselves.

[d]SP - Slagging pyrolysis and packaging.

[e]CPT - Compaction, immobilization, and packaging.

[f]PKG - Repackaging only.

During processing, a whole-body dose commitment of 1.9×10^{-7} mrem per year of operation or 3.6×10^{-3} mrem to the bone could be expected at the point of maximum airborne concentration.

During handling associated with shipment of processed waste to the INEL disposal locations, workers would be exposed to direct radiation from the waste packages. Experience indicates that these doses to the workers may be as much as 400-500 mrem/yr.

There would be no radiological exposures to the general population during normal operations. The dominant handling accident would be associated with the waste that has only been repackaged. The resulting maximum individual dose commitment to the lung would be approximately 2×10^{-5} mrem for each occurrence.

Over the long term (i.e., over more than about 100 years), natural disasters (floods, volcanoes, etc.) could occur, disrupting the waste and resulting in release of radionuclides. In terms of radiation dose, volcanic action was determined to be the predominant event for all of these alternatives. Although significant 50-year dose commitments (up to 90 rem to the lung) could be delivered to maximally exposed individuals, no near-term fatalities from radiation would be expected to result from such an event.

Nonradiological effects from any of the three alternatives discussed above would generally be limited to minor commitments of energy, resources, and labor. An exception is the large requirement of concrete for the massive structures for engineered surface disposal and for engineered shallow land disposal. The latter facility can be made less massive, using less concrete, with little sacrifice in long-term safety. This reduction in mass is probably not possible for the engineered surface-disposal facility, which would be openly exposed to the elements in an area of severe winters; significant rates of deterioration of the containment would then be expected over the long term.

Slagging pyrolysis would be the most costly of the processing methods studied, but the resulting waste product would be the safest. The processing cost for compaction and immobilization would be slightly higher than that for repackaging only. However, the reduced disposal costs resulting from the decreased volume would more than offset this slight difference. Compaction and immobilization would also have a small advantage in the safety of the disposed waste product. The less massive variation of engineered shallow-land disposal would cost about one-fourth to one-half as much as the other methods studied.

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10 Unavoidable Adverse Impacts of the Reference Case

10.1 CONSTRUCTION

For the reference case, the impacts of construction will be like those of other large building projects. They include increased noise levels near the site, increased air pollution due to earth-moving and to vehicular activity, and the disruption of existing land uses on the site and along new road and utility rights-of-way.

Approximately 620 acres will be removed from rangeland and wildlife habitat during both the construction and the operation phases of the plant. An additional 360 acres will be temporarily disrupted during construction. Details of acreages committed are given in Section 9.1.1. Although scaled quail, mourning dove, and mule deer will lose some habitat, the losses will be insignificant because extensive areas of similar habitat exist throughout the site region. A loss of individuals of the more sedentary species (e.g., rodents, lizards) during construction will have an insignificant impact on the population of these species in the area. The site and most areas in which land will be disturbed are rangeland where 60 to 64 acres per animal-year has been an acceptable grazing capacity. However, the recent average density of grazing on the lands in and around the site has been about one head per 100 acres. Therefore, the loss of grazing land will mean a reduction in grazing capacity of 10 to 11 animals.

Most of the construction workers are expected to reside in Carlsbad and Hobbs, New Mexico. Although some of the workers will be drawn from the local labor force, many workers will move into the area to work on the project, increasing the demands on existing community services and community resources. In Carlsbad a temporary housing shortage may develop; it would be met by the development of trailer parks or other temporary accommodations. In Hobbs the capacity of the school system is now expected to be exceeded by 1983; if a major fraction of the construction workers choose to live in Hobbs, the capacity may be exceeded 1 year earlier. Highway use within Eddy and Lea Counties will increase because of the commuting of construction workers and the transport of construction materials.

These impacts of the influx of construction workers will require increased public expenditures; operating costs will increase. Because revenues normally lag behind expenditures, local governments may experience some short-term problems in meeting the demands for new public services. The communities, however, are already capable of planning to meet these impacts, which will be mitigated or offset by increased tax revenues, decreased unemployment, and highway improvements associated with the construction of the plant.

10.2 OPERATION

During the operation phase, approximately 620 acres of land will remain unavailable for rangeland and wildlife habitat. The impacts of this removal are discussed in Section 10.1.

The mined-rock pile will grow and become a more obvious feature of the landscape. Rainwater falling on it will dissolve some salt and sterilize the soil under the pile and in the surrounding ditch. Some salt will be blown onto the surrounding land and may cause changes in vegetation.

The main access to the plant will be U.S. Highway 62-180. Although traffic levels will increase, this highway's capacity will be adequate both for the workforce and for trucks transporting waste to the plant. Certain segments of the road to Hobbs to the east of the site may need to be upgraded.

The increase in area population will result in an increased demand for primary health care. Current physician-to-population ratios are not at the levels recommended by Bennett (1977), although hospital facilities are adequate.

The development of the site and facilities will deny the future recovery of potash and oil and gas beneath the site. These are discussed in Sections 9.1.4 and 11.1.

Operation of the plant will release some radioactivity. The greatest annual dose commitment is to the bone and is estimated to be 1.5×10^{-4} rem (0.15% of 50-year background radiation) for an individual living at the James Ranch. The population exposure (whole body) is estimated at 3.8×10^{-6} man-rem, spread over 96,000 persons.

Transportation of waste to the plant will expose to radiation people near the transportation routes. The average radiation dose to these people will be a small fraction of the natural background dose; furthermore, it will be a small fraction of the limits recommended for members of the general public from all sources of radiation other than natural and medical sources.

The final shutdown of the plant will narrow the economic base of nearby communities.

REFERENCE FOR CHAPTER 10

Bennett, M. D., 1977. "Medically Underserved Areas of New Mexico," Working Paper, School of Medicine, University of New Mexico.

11 Irreversible and Irretrievable Commitments of Resources for the Reference Case

11.1 LAND USE

Approximately 140 acres of land will be occupied by surface facilities for the duration of repository operation. This land includes 30 acres for the surface storage of excess salt mined from the repository. Approximately 480 acres will be used for the roads and railroad. Most of this 620 acres will be restored to its original contours, reseeded, and permitted to revert to its natural state after plant decommissioning. After final removal of the mined-rock pile, the 30 acres that it covered will be regraded and reseeded. Full recovery of the area is expected to require several decades.

These predictions of land-use commitments assume that the surface facilities will be razed during decommissioning. If they are mothballed instead, the land they occupy and the associated access roads will remain committed.

11.2 DENIAL OF MINERAL RESOURCES

As discussed in Section 9.1.4, development of the WIPP reference repository will deny access to portions of local deposits of hydrocarbons and potash minerals. The most significant of these is langbeinite, an ore that is rich in potassium and magnesium and has commercial value as a chemical fertilizer. In the United States langbeinite is found only in the Carlsbad Potash Mining District, where the resources will probably be depleted in less than 70 years. The langbeinite reserve beneath the site proposed for the reference case is 13 million tons, equivalent to 5 years' production of such ore at Carlsbad. Thus, development of the repository will require an earlier transition to other chemical fertilizers.

The site also overlies about 25 billion cubic feet of natural gas and 350,000 barrels of distillate. These amount to less than 0.02% of the U.S. reserves of these resources. The existence of the repository does not necessarily preclude access to the underlying hydrocarbons permanently. They may eventually become available through the use of such techniques as slant-hole drilling from outside control zone III or through a future relaxation of the controls now thought prudent for the area.

11.3 RESOURCES FOR CONSTRUCTION

As discussed in Section 9.1.2, the following resources will be required over the 4-year construction period of the WIPP reference repository:

Concrete	125,000 barrels (portland cement)
Steel	15,000 tons
Copper	150 tons
Aluminum	200 tons
Lumber	500,000 board-feet
Water	19 million gallons
Electricity	4 million kilowatt-hours
Propane	140,000 gallons
Diesel fuel	1.5 million gallons
Gasoline	940,000 gallons

None of these amounts will exceed 1% of the U.S. production over the construction period.

11.4 RESOURCES FOR OPERATION

As discussed in Section 9.2.2, the following resources will be used by the plant during its operation:

Electrical power	20,000 kilowatts
Diesel fuel	400 gallons per day
Gasoline	140 gallons per day
Water	25,000 gallons per day

These modest requirements will not significantly affect the local or regional availability of these resources.

12 Relation of the Reference Case to Land-Use Plans, Policies, and Controls

12.1 EXISTING LAND-USE PLANS, POLICIES, AND CONTROLS

As described in Section 8.1, 17,200 acres of the site proposed for the reference case are Federal land, 1760 acres are State land, and none is private land. All this land is presently leased for grazing, 25% is subject to potash leases, and 35% is subject to hydrocarbon leases, with some overlap (Table 8-2).

There are no State, county, or local land-use policies, plans, or controls on this land. There is a "State of New Mexico Policy on Nuclear Waste Disposal," but it does not explicitly refer to the use of the land itself. This policy is discussed in Chapter 14.

The Federal land is administered by the Bureau of Land Management (BLM) of the U.S. Department of the Interior; the State land is administered by the Commissioner of Public Lands of the State of New Mexico. Other Federal and some State agencies have jurisdiction over certain of the resources in these lands. These include the U.S. Geological Survey, which administers the development of mineral resources by issuing drilling permits and approvals for exploration and mining, and the New Mexico Department of Game and Fish, which promulgates hunting regulations for all lands in the State, including Federal lands.

The proposed land-withdrawal area is within the BLM's East Eddy Planning Unit. The BLM manages land under its control by means of a formal land-use planning system. For this planning unit, the BLM has completed a Unit Resource Analysis, which identifies inventories, problems, conditions, use, and management potentials. This information is being used to develop a Management Framework Plan (MFP) indicating decisions on the coordinated management of resources and broad-based functional guidelines for the entire planning unit. Although the comprehensive MFP for this unit is scheduled for completion in 1979, guidelines developed in an earlier MFP are still applicable to the site proposed for the reference case; they state that the BLM will

1. Encourage exploration for oil and gas and for potash.

2. Restrict or control other surface uses that conflict with oil and gas or potash development.

3. Manage intensively for recreational uses.

4. Encourage livestock use and management, developing Allotment Management Plans (AMPs) for the unit. (The James Ranch encompassing the southern 65% of the proposed withdrawal area is already party to an AMP; the Crawford Ranch is not.)

The National Historic Preservation Act of 1966 (16 U.S.C. Section 470-70n), Executive Order No. 11593 (Federal Register, Vol. 36, p. 8921, 1971), and Public Law 93-291 (May 24, 1974) are related to the preservation of

cultural, historical, archaeological, and architectural resources. There will be no conflict with these requirements, because all construction and other activities that will disturb the surface are preceded by archaeological surveys that guide the preservation of these resources.

As stated in detail in Chapter 14, the activities of the WIPP reference repository will comply with all applicable Federal, State, and local requirements for protection of the environment.

12.2 COMPATIBILITY OF THE REFERENCE CASE WITH EXISTING LAND-USE PLANS

The BLM policies and plans encourage exploration for hydrocarbons and potash and also encourage recreation and well-managed grazing to the extent that they do not conflict with mineral exploration.

Section 9.1.4 describes the oil and gas resources of the site proposed for the reference case and the extent to which the proposal conflicts with their exploration. It is clear that the withdrawal of control zones I, II, and III from mineral exploration and development is incompatible with the goal of encouraging exploration for oil and gas. However, the existence of the repository does not necessarily preclude access to these resources permanently. They may eventually become available for exploitation through the use of such techniques as slant-hole drilling from outside control zone III or by a future relaxation of the controls now thought prudent for the area.

The potash resources and the extent of conflict with them are also described in Section 9.1.4. The proposal conflicts with the BLM's goal of encouraging the exploration of these resources. It is possible, however, that mining of the potash levels 300 feet above the upper level of the repository will eventually be found compatible with the repository.

Because of site-exploration efforts, the road network in the area has already been expanded from about 8 miles of low-quality road to 28 miles of caliche-surfaced road. The new roads are already allowing more recreational use, principally for hunting. In this respect, therefore, the reference case is compatible with BLM plans to encourage recreation.

Cattle grazing is now permitted by the BLM at an estimated six head per square mile on the Federal lands within the proposed site. The DOE intends to allow grazing to continue at this stocking rate (or to adjust to BLM future practices) except for 620 acres devoted solely to the plant and an additional 360 acres required during construction. In this respect, the reference case is slightly incompatible with BLM plans for grazing.

In summary, the proposed WIPP reference repository is somewhat in conflict with BLM plans for this land.

13 Relationship Between Short-Term Uses and Long-Term Productivity at the Reference Site

The WIPP will provide a permanent repository for isolating transuranic wastes from the biosphere for thousands of years. It will afford long-term protection to the public from the possible release of radioactivity contained in transuranic waste materials generated in national defense programs. In the short term, the repository will offer an opportunity to test disposal methods for high-level radioactive waste and to demonstrate the disposal of spent reactor fuel; the knowledge and experience gained from this opportunity will advance the state of the art of waste disposal in bedded salt. These missions support national defense and energy policies (Deutch, 1978; IRG, 1979; OSTP, 1978).

Use of the site as a transuranic-waste repository will permanently restrict the extraction of mineral resources above and below the repository. The types and quantities of these resources are discussed in Section 9.1.4 in the context of regional and national reserves.

Approximately 620 acres of land that is currently rangeland and wildlife habitat will be used for surface facilities, transportation routes, and the mined-rock pile. After decommissioning, which may take place several decades after the repository is built, most of this area will be allowed to return to its natural state; the recovery time for the disturbed area is expected to be several decades.

REFERENCES FOR CHAPTER 13

Deutch, J. M., 1978. Report of the Task Force for Review of Nuclear Waste Management (draft), U.S. Department of Energy, Washington, D.C., DOE/ER-0004/D.

IRG, 1979. Report to the President by the Interagency Review Group on Nuclear Waste Management, TID-29442, U.S. Department of Energy, Washington, D.C.

Office of Science and Technology Policy (OSTP), 1978. Isolation of Radioactive Wastes in Geologic Repositories: Status of Scientific and Technological Knowledge (draft), Executive Office of the President, Washington, D.C.

14 Environmental Approvals and Consultations: Reference Case

14.1 REVIEWS AND APPROVALS

As a Federal agency, the U.S. Department of Energy (DOE) complies with the National Environmental Policy Act (NEPA) of 1969, 42 U.S.C. Sections 4321 et seq. (1970). In addition, the DOE is complying with Executive Order 12088 (Federal Register, Vol. 43, p. 47707, October 17, 1978) and Office of Management and Budget Circular A-106, relating to the prevention, control, and abatement of environmental pollution at Federal facilities, as well as certain provisions of the Clean Air Act, as amended, 42 U.S.C.A. Section 7401 et seq. (1977), the Clean Water Act (Public Law 95-217), and the Solid Waste Disposal Act, as amended, 42 U.S.C. Sections 3251 et seq. (Public Law 94-580).

In accordance with Section 313 of the Clean Water Act and Section 118 of the Clean Air Act, the DOE will comply with all Federal, State, interstate, and local requirements for the control and abatement of pollution to the same extent as any nongovernmental person. In accordance with Title 40 of the Code of Federal Regulations, which implements these acts, the DOE will obtain a Prevention of Significant Deterioration permit from the U.S. Environmental Protection Agency (or from the State of New Mexico, if authority has been transferred by the date of the application). Similarly, in accordance with Section 6001 of the Solid Waste Disposal Act, the operation of a landfill for nonradioactive-solid-waste disposal at the WIPP reference repository will comply with all Federal, State, interstate, and local requirements, both substantive and procedural. No permit under Section 402, National Pollutant Discharge Elimination System, of the Clean Water Act is expected to be required for the project since no liquid effluents will be discharged as a result of facility operation.

Applicable State and local requirements can be summarized as follows:

a. "New Air Contaminant Source" construction permits will be obtained from the New Mexico Environmental Improvement Division pursuant to the New Mexico Air Quality Control Act, Section 12-14-7, NMSA 1953, and Section 702 of the New Mexico Air Quality Standards and Regulations, with respect to emissions from the operation of equipment fueled with diesel oil, gas, and oil.

b. Plans for sewerage systems, either temporary or permanent, will be filed, in advance of construction, with the New Mexico Water Quality Control Commission pursuant to the New Mexico Water Quality Act, Section 75-39-4.1, NMSA 1953, and Section 1-202 of the New Mexico Water Quality Regulations.

c. A registration certificate will be obtained from the New Mexico Environmental Improvement Division for the on-site sanitary landfill pursuant to Section 103 of the New Mexico Solid Waste Management Regulations.

Applications for such permits and certificates, and filing of the pertinent plans, will have to await the completion of facility design.

The DOE will also be consulting with the Department of Transportation (DOT) and the NRC on transportation safety.

The DOE will require the operating contractor of the repository to carry adequate insurance against public liability for nonnuclear risks. With respect to public liability for nuclear risks, however, the DOE intends to enter into an indemnity agreement with the operating contractor, as permitted under the Price-Anderson Act (Section 170.d of the Atomic Energy Act of 1954, as amended). Such an indemnity agreement will also apply to nuclear incidents that might occur in the course of waste transportation to or from the repository.

The DOE is complying with the National Historic Preservation Act of 1966 (16 U.S.C. Sections 470-470n); Executive Order No. 11593 (Federal Register, Vol. 36, p. 8921, 1971); and Public Law 93-291 (May 24, 1974), which relate to the preservation of cultural, historical, archaeological, and architectural resources. In compliance with these requirements, an archaeological and historic site survey was made in 1976 of the central 4 square miles of the reference site (Nielsen, 1976). Archaeological clearances have also been obtained from the Bureau of Land Management for all new roads, drilling or operational pads, and off-road seismic lines and resistivity surveys. The Nielsen report was submitted to the State Historic Preservation Officer for New Mexico to determine whether any of the cultural resources found warrant nomination in the State or National Register of Historic Places. As a result (the correspondence is reproduced in Appendix I), the reference site has been declared eligible for nomination as an archaeological district.

The DOE is also complying with the Endangered Species Act of 1973 for the conservation of endangered and threatened biota and their habitat (Public Law 93-205). As indicated in Section 7.1 and Appendix H, no animals or plants listed on the Federal lists of endangered species have been found at or near the site, although one bird was found that is on the State list of species whose prospects for survival are likely to be in jeopardy within the foreseeable future.

No determination or permits will be required from the Federal Aviation Administration because no plant structures will be more than 200 feet higher than the local terrain.

The necessary Federal lands required for the site will be acquired through a legislative withdrawal action. Utility easements and transportation rights-of-way will be acquired through easements from the Bureau of Land Management in accordance with the Federal Land Policy and Management Act of 1976 (Public Law 94-579, Section 507).

14.2 CONSULTATIONS

In developing various portions of this Draft Environmental Impact Statement (DEIS), the DOE has contacted the following agencies:

New Mexico State Land Commission
New Mexico Environmental Improvement Division
New Mexico Highway Department
Federal Aviation Administration
U.S. Department of Agriculture, Soil Conservation Service
U.S. Department of the Interior, Bureau of Land Management
U.S. Environmental Protection Agency
U.S. Geological Survey
U.S. Army Corps of Engineers
Carlsbad, New Mexico, municipal authorities
Eddy County, New Mexico, authorities

The DOE has also consulted the following agencies, organizations, and officials about the construction and operation of the WIPP reference repository and its implications on the development of the area:

Organization or official	Dates
American Association of State Geologists and the Geological Review Group, U.S. Geological Survey	5/77
Toney Anaya, former New Mexico Attorney General	4/78, 9/78
Jerry Apodaca, former New Mexico Governor	1975-1978
Bureau of Land Management (Santa Fe and Roswell)	1/76, 6/76, et al.
California Energy Resources Conservation and Development Commission	10/77
Pete Domenici, U.S. Senator, and staff	4/77, 7/78, 11/78
Robert Ferguson, former New Mexico Lt. Governor	2/78
General Accounting Office	6/76
Walter Gerrels, Mayor of Carlsbad	7/75, 8/75, 9/75, 8/76, 9/76 11/76, 3/77, 11/77, 3/78
Bruce King (now Governor of New Mexico)	1/78, 2/78, 8/78
National Academy of Sciences	4/78, 6/78, 7/78
New Mexico Advisory Committee on the WIPP	1/78

Organization or official	Dates
New Mexico Energy Resources Board	3/76
New Mexico Environmental Improvement Agency (now Division)	11/75, 8/76, 4/77, 10/77, 11/77
New Mexico Governor's Technical Excellence Committee--Subcommittee on Radioactive Wastes	7/75, 10/75, 1/76, 7/76, 11/76 2/77, 4/77, 5/77, 1/78
New Mexico Legislative Committees on Energy	10/75, 7/76, 2/77, 1/79
New Mexico Senate Conservation Committee	1/78
New Mexico State Land Commission	1/76, 7/76
Office of Management and Budget	8/76
Office of Science and Technology Policy	6/78
Harrison Schmitt, U.S. Senator, and staff	7/77, 3/78, 7/78, 11/78
Southeastern New Mexico Economic Development Division	12/75
U.S. Department of Justice	3/28
U.S. Environmental Protection Agency	1/76, 5/77
U.S. Nuclear Regulatory Commission	10/75, 1/76, 8/76, 11/76, 3/77 5/77, 10/77, 11/77, 1/78, 2/78
Utilities Waste Management Group	2/78

In addition, a Federal-State-Local Review group has been established and has met numerous times (June 1976, September 1976, January 1977, December 1977, and June 1978). This group consists of representatives of the following agencies:

Federal Agencies

Army Corps of Engineers
Bureau of Land Management
Bureau of Mines
Department of the Interior
Environmental Protection Agency
Federal Aviation Administration
Federal Energy Administration
Federal Highway Administration
Federal Railroad Administration
Fish and Wildlife Service
Mine Safety and Health Adminstration
National Park Service
Nuclear Regulatory Commission
Occupational Safety and Health Administration
Soil Conservation Service
U.S. Geological Survey

State of New Mexico

Department of Health and Social Services
Energy Resources Board
Environmental Improvement Administration
New Mexico Energy Institute
Office of the State Geologist
Oil and Gas Conservation Commission
State Engineer's Office
State Highway Department
State Planning Office

State of Texas

Governor's Energy Advisory Council
Radiation Control Agency

Eddy County

Eddy County Commission
State Senator from Eddy County, Joseph Gant

City of Carlsbad

Department of Development

Other

Western Interstate Nuclear Board

The DOE has provided $2.6 million to the State of New Mexico to establish an Environmental Evaluation Group (EEG) to perform an independent technical review of the WIPP reference repository for the State of New Mexico. The group is studying health, safety, and environmental impacts, as well as mitigation methods. It will report its findings to the New Mexico Environmental Improvement Division, the Secretary of Health and Environment, the Governor, and the DOE. The State will use the EEG's findings as a major portion of its input to the NRC's licensing process and to its own judgment of the overall merits and desirability of the WIPP reference repository.

14.3 PUBLIC COMMENT

The DOE has met with numerous environmental and public interest groups during the history of the project. Among these are:

- League of Women Voters
- Natural Resources Defense Council
- New Mexico Wildlife Federation
- Reserve officers' group
- Senior citizens' group
- Sierra Club
- Citizens' workshop (Las Cruces, NM)
- Bernalillo County Democratic Forum
- Women's Junior League (Fort Worth, TX)

Public reading rooms have been established in Albuquerque, Carlsbad, and Las Cruces, New Mexico. A total of 11 public meetings were conducted; transcripts of the meetings have been prepared and placed in the public reading rooms.

Location	Date
Carlsbad, NM	4/11/78 (two meetings)
Albuquerque, NM	4/12/78 (two meetings)
Santa Fe, NM	4/14/78
Midland, TX	7/11/78
Amarillo, TX	7/12/78
El Paso, TX	7/13/78
Las Cruces, NM	8/10/78
Roswell, NM	11/15/78
Hobbs, NM	1/4/79

Notice of intent to prepare this DEIS was published in the Federal Register on July 14, 1978 (Vol. 43, p. 30331). Thirty-six letters were received as a result. The writers were, in order of receipt of their letters:

1.	Phillip L. Boucher	Mesilla Park, NM
2.	Thomas A. Parkhill	Albuquerque, NM
3.	Vernon E. Arnold	Santa Fe, NM
4.	Dan McNabb, Industrial Development Corporation of Lea County	Hobbs, NM
5.	Bill Weidenhofer et al., New Mexico Organic Growers Assocation	Albuquerque, NM
6.	Arthur V. Capps	Roswell, NM
7.	Don Schrader	Albuquerque, NM
8.	Neal Weinberg	Albuquerque, NM
9.	Edith Kirby, New Mexicans for Survival	Albuquerque, NM
10.	John W. Hernandez, Sr.	Las Cruces, NM
11.	Mrs. Rosalee Holcombe	(address not given)
12.	Mrs. R. Wilcox	Albuquerque, NM
13.	Martin Nix	Albuquerque, NM
14.	Dudley R. Slade	Albuquerque, NM
15.	Ronnie D. Lipschutz, Union of Concerned Scientists	Cambridge, MA
16.	Robert E. Lyons	Albuquerque, NM
17.	Mrs. Barbara Kramer	Sante Fe, NM
18.	Mrs. F.J. Dekleva	(address not given)
19.	Kathleen Halleck	(address not given)
20.	David L. Nussear	Albuquerque, NM
21.	David Berick, Environmental Policy Center	Washington, D.C.
22.	R. D. Enz	(address not given)
23.	Barbara L. Clutter, M.D.	Santa Fe, NM
24.	William B. Anderson	(address not given)
25.	Judy Sellers	(address not given)
26.	Debra J. Hancock	(address not given)
27.	Peg Welk	(address not given)
28.	Cathy Sullivan	(address not given)
29.	J. M. Mobley, Department of Finance and Adminstration, State of New Mexico	Santa Fe, NM
30.	Women's Health Services	Santa Fe, NM
31.	John L. Hill, Attorney General of Texas	Austin, TX
32.	Constance Mills Atkins	Corrales, NM
33.	R. E. Drumheller	(address not given)

34. Nick Franklin, Secretary, Energy and Minerals Department, State of New Mexico — Santa Fe, NM
35. Senaida Chavez y Pinckard — Albuquerque, NM
36. Randolph E. Scheffel, Durita Development Corporation — Naturita, CO

Most of the 36 letters did not comment on the contents of the proposed DEIS but took the opportunity to express their feelings about the repository. Most of the letters were from within the State of New Mexico; of those whose addresses could be made out, only four came from out of State.

Twenty of the thirty-six letters expressed opposition to the WIPP, most of them passionately so, calling it a violation of states' rights and an imposition of a dumping ground on New Mexico, and worrying about health and safety and about spoiling a presently clean environment. Most argued against the creation of any more waste. Some mentioned solar power as the way to meet the country's energy needs; others suggested conservation, transmutation, rocketing the waste into the sun, leaving it where it is, and sending it to Alaska. One person asserted that there is no safe way to dispose of nuclear waste.

Eleven of the thirty-six letters expressed some degree of approval of the WIPP, including six who were willing to leave the decision to the experts.

Five of the letters were neutral.

The principal questions, issues, and suggestions coming out of these meetings and these letters, and the sections of this DEIS where they are taken up are listed below. A breakdown of the comments in the 36 letters and a correlation with positions against, for, or neutral to the WIPP are given in Table 14-1.

1. Need for nuclear power. Those speaking or writing against the WIPP are usually against nuclear power and nuclear weapons and question the need for generating any waste at all. Those for the WIPP cite the need for nuclear power. This DEIS does not speak to the need for nuclear power because it is outside its scope; instead this document cites the existence now of large quantities of waste that need to be disposed of permanently.

2. Transportation. Many of the opponents of the WIPP assert that accidents are certain and that accidents will release large, dangerous amounts of radioactivity. Some persons question routing, and the State questions the adequacy of roadbeds within the State. Accidents are treated in this DEIS in Section 6.7. The adequacy of shipment systems has already been the subject of an NEPA process reported in a document issued by the NRC (1977). Shipment systems are also examined in Chapter 6 of this DEIS.

3. Insurance. This matter usually arises in the context of transportation accidents and is raised by opponents of the WIPP. Often cited is the exclusion of such coverage in home-owner insurance policies. The matter is treated elsewhere in this chapter: insurance for loss either during operations or during transportation is assured by the government.

4. Mineral resources. As stated elsewhere in this DEIS (Sections 7.2.7, 9.1.4, 9.2.4, 10.2, and 11.2), development of the WIPP will deny access to some oil and gas and to some potash minerals.

5. Retrieval. If waste for any reason has to be removed from the WIPP, transportation risks will be incurred anew, and there is a question about where it can be taken next. Retrieval methods and impacts are discussed in Section 8.11. This document does not specifically address the question of further transportation risks, but they are essentially identical with those involved in transferring waste to the WIPP. The Interagency Review Group recommends that regional repositories be set up (IRG, 1979, p. 51); waste removed from the WIPP would be sent to one of the other repositories.

6. Monitoring. This issue is principally raised by the State, who wish to know in detail what the plans are for the operational and post-operational periods. The matter is discussed, so far as present plans permit, in Appendix J.

7. Socioeconomics. The questions are about the economic impacts of the WIPP on southeastern New Mexico, the number of jobs, population changes, pressures on community facilities, etc. These matters are discussed in Section 9.4. Also asked is whether Federal impact funds will be available. This matter is not settled.

8. Dissolution. There are numerous dissolution features in southeastern New Mexico. Anderson (1978) reports deep dissolution (solution from below) in Texas to the south. These facts suggest dangers to the long-term integrity of the WIPP. The matter is discussed in Sections 7.3.4 and 9.5.1. The conclusion is that the processes involved are too slow to affect the integrity of the WIPP.

9. Brine and gas pockets. The public sometimes attributes the abandonment of the first site in the Delaware basin to a brine pocket encountered by a drill hole in the Castile Formation. Anderson (1978) speaks also of gas pockets in the Salado Formation. The matter is discussed in Section 7.2, and it is concluded that they do not present a hazard to the WIPP.

10. More sites in New Mexico? There are two questions involved here, whether the existence of the WIPP will attract other related industry and whether other repositories will be developed nearby. These questions are not discussed in this DEIS, as they are too speculative to admit of definite answers.

Table 14-1. Issues Brought up in Letters of Comment

Issue	Mentioned by those			Total mentions
	Against	For	Neutral	
1. Need for nuclear power	8	7	2	17
2. Transportation risks	8	0	3	11
3. Insurance against accidents	2	0	1	3
4. Mineral resources	2	0	1	3
5. Retrieval	0	0	5	5
6. Monitoring	0	0	1	1
7. Socioeconomics	1	3	0	4
8. Dissolution	0	0	2	2
9. Brine and gas pockets	0	0	1	1
10. More sites in New Mexico?	0	0	2	2

Letter No. 34 includes, among other things, a statement of the State of New Mexico policy on nuclear waste disposal: "The state's principal objective is to assure that the WIPP proposal is consistent with the economic, social, environmental, and public health interests of its citizens. The basic goal of the state is to become sufficiently well informed of the implications of waste disposal in New Mexico so that an intelligent choice can be made regarding the project." In this context the State has adopted certain policy positions and proposes certain implementation measures. These include:

1. State right of concurrence
2. Licensing by the NRC
3. Federal responsibility for accidents
4. An independent evaluation by the State
5. State monitoring of waste-disposal activities
6. Insistence on technical conservatism
7. Insistence on retrievability until shown safe
8. Insistence on retrievability of spent fuel for reprocessing
9. Insistence on a full transportation analysis
10. Concern over existing DOE burial grounds
11. Possible other Federal investments
12. Compensation for losses of revenue
13. Rail and road bypasses around New Mexico communities

REFERENCES FOR CHAPTER 14

Anderson, R. Y., 1978. Deep Dissolution of Salt, Northern Delaware Basin, New Mexico, University of New Mexico (written under contract with Sandia Laboratories).

IRG, 1979. Report to the President by the Interagency Review Group on Nuclear Waste Management, TID-29442, U.S. Department of Energy, Washington, D.C.

Nielsen, J., 1976. An Archaeological Reconnaissance of a Proposed Site for the Waste Isolation Pilot Plant (WIPP), SAND77-7024, Sandia Laboratories, Albuquerque, N.M. Reprint of An Archaeological Reconnaissance of Sandia Laboratories' Los Medanos Nuclear Waste Disposal Facility, Eddy County, New Mexico, same author. Agency of Conservation Archaeology, Eastern New Mexico University, Portales.

NRC (U.S. Nuclear Regulatory Commission), 1977. Final Environmental Statement on the Transportation of Radioactive Material by Air and Other Modes, NUREG-0170, Vols. 1 and 2.

Glossary

actinide	An element in the series beginning with element 89 and continuing through element 103. All the transuranic nuclides considered in this document are actinides.
activity	A measure of the rate at which a material emits nuclear radiation, usually given in terms of the number of nuclear disintegrations occurring in a given length of time. The unit of activity used in this document is the curie (Ci).
alpha particle	A positively charged particle emitted in the radioactive decay of certain nuclides. Made up of two protons and two neutrons bound together, it is identical to the nucleus of a helium atom. It is the least penetrating of the three common types of radiation--alpha, beta, and gamma radiation.
anhydrite	A mineral consisting of anhydrous calcium sulfate: $CaSO_4$. It is gypsum without its water of hydration and is harder and less soluble than gypsum.
annealing	Originally, to heat and cool again slowly to soften glasses or metals. In this document, to heat to the point where imperfections disappear.
anticline	A fold of rocks whose core contains the stratigraphically older rocks; it is convex upward.
B (shipment type)	A classification (10 CFR 71) of shipments of radioactive material depending on the amount of radioactivity contained; broadly characterized, type B shipments contain more radioactivity than type A shipments of similar radioactivity and potential hazard. Federal regulations also specify standards for the packaging of shipments according to type.
background (radiation)	Radiation in the human environment from naturally occurring elements, from cosmic radiation, and from fallout.
bare waste	High-level waste that is not enclosed in a canister; such waste will be used in some experiments in the WIPP.
basalt	A dark igneous rock, usually formed as lava flows.
bedded salt	Consolidated layered salt separated from other layers by distinguishable planes of separation.
beta particle	A negatively charged particle emitted in the radioactive decay of certain nuclides; a free electron.
biological half-life	The time required for an organism to eliminate half the amount of a radionuclide ingested or inhaled.

brine inclusion	A small opening in a rock mass (salt) containing brine; also the brine included in such an opening. Some gas is often also present.
canister	As used in this document, a container for remote handled waste, spent fuel, or high-level waste, usually cylindrical. The waste will remain in this canister during and after burial in salt. A canister affords physical containment but not shielding; shielding is provided during shipment by a cask.
Capitan Reef	A fossil limestone reef of Permian age that rings the Delaware Basin except in the south.
Carlsbad Potash District	The area east of Carlsbad and north and west of the WIPP site formally designated by the U.S. Geological Survey as having potentially economic grades of potash mineralization.
cask	A massive shipping container providing shielding for highly radioactive materials and holding one or more canisters.
Castile Formation	A formation of evaporite rocks (interbedded halite and anhydrite) of Permian age that immediately underlies the Salado Formation in which it is proposed that the WIPP reference repository be built.
chain reaction	A reaction that stimulates its own repetition. In a fission chain reaction, a fissionable nucleus absorbs a neutron and splits, releasing additional neutrons. A fission chain reaction is self-sustaining when the number of neutrons released equals or exceeds the number of neutrons lost by escape from the system or by non-fission absorption.
clastic rock	Rock made up of broken fragments of preexisting rocks.
commercial waste	Nuclear waste deriving from commercial sources. These are principally power reactors, but also include research laboratories and medical facilities.
contact-handled waste	Waste that does not require shielding other than that provided by its container.
containment	The retention of radioactivity within a system to the exclusion of its release to the biosphere in unacceptable quantities or concentrations.
contamination	Undesirable radioactive material present on outside surfaces. This contamination can be either transferrable or fixed. Radiation penetrating the walls of a waste package from within is not contamination.
control zone	At the WIPP, one of four areas of land whose use is governed by controls and restrictions.

creep closure	Closure of underground openings, especially openings in salt, by plastic flow of the surrounding rock under lithostatic pressure.
criticality	The state of a mass of fissionable material when it is sustaining a chain reaction.
critical mass	The smallest mass of fissionable material that will support a self-sustaining chain reaction. The critical mass depends on its shape and the nature of the surrounding material because these influence the ease with which neutrons can escape and the likelihood that they will be reflected back in the mass.
Culebra dolomite	A layer of dolomite within the Rustler Formation that is locally water-bearing.
decay, radioactive	The decrease in the number of radioactive nuclei present in a radioactive material due to their spontaneous transmutation. Also, the transmutation of a radionuclide into another nuclide by the emission of a charged particle.
decommissioning	The process of removing a facility from operation. It is then mothballed, entombed, decontaminated and dismantled, or converted to another use.
decontamination	The removal of unwanted material (especially radioactive material) from the surface or from within another material.
decontamination factor (DF)	The reduction in radionuclide concentration or surface-level activity resulting from filtering or cleaning, measured as the ratio of activity before and after filtering or cleaning.
defense waste	Nuclear waste deriving from the manufacture of nuclear weapons and the operation of naval reactors. Associated activities such as the research carried on in the weapons laboratories also produce defense waste.
Delaware basin	An area in southeastern New Mexico and adjacent parts of Texas where a sea deposited large thicknesses of evaporites some 200 million years ago. It is partially surrounded by the Capitan reef.
diapir	A geologic flow structure, either a dome or an anticline, in which overlying rocks have been ruptured by the flow upwards of a plastic core material such as salt.
disposal	In this document, permanent disposition of waste in a repository. Use of the word "disposal" often implies no expected need for later retrieval. It also implies a minimal need for surveillance.

dissolution front	The boundary of a geologic region within which salt is dissolving. In this document, the term particularly refers to the wedge-like leading edge of dissolution at the interface between the Rustler and the Salado Formations.
dolomite	A sedimentary rock consisting mostly of the mineral dolomite [$CaMg(CO_3)_2$]. It is commonly found with limestone and usually is formed from limestone by replacement of calcium by magnesium.
dome (breccia pipe)	A type of hill found near the WIPP reference site; under at least some of these hills lies a zone of breccia (rock reconstituted from coarse rock fragments).
dome, salt	A diapiric or piercement structure with a central, nearly circular salt plug, generally one to two kilometers in diameter, that has risen through the enclosing sediments from a deep mother bed of salt.
dose (radiation)	A general term indicating the amount of energy absorbed per unit mass from incident radiation. The standard unit of dose to humans is the rem.
dose commitment	In this document, a less formal expression meaning dose equivalent commitment.
dose equivalent	The product of absorbed dose and modifying factors that take into account the biological effect of the absorbed dose. While dose includes only physical factors, dose equivalent includes both physical and biological factors and provides a radiation-protection scale applicable to all types of radiation. Units are rem for an individual and man-rem for a population group.
dose equivalent commitment	The total dose equivalent that results from an intake of radioactive materials during all the time from the intake to death of the organism. For humans the dose is usually evaluated for a period of 50 years from the intake. Units are man-rem.
dose rate	The rate at which dose is delivered.
drift	A mine passageway cut parallel to the course of a rock stratum.
emplacement medium	The material in which a repository is built and into which the waste will be placed.
evaporite	A sedimentary rock composed primarily of minerals produced by precipitation from a solution that became concentrated by the evaporation of a solvent, especially salts deposited from a restricted or enclosed body of seawater or from the water of a salt lake. In addition to halite (NaCl) these salts include potassium, calcium, and magnesium chlorides and sulfates.

exclosure	A biological study site from which grazing and browsing animals are excluded.
fault	A surface or zone of rock fracture along which there has been displacement.
fault tree	A tree-like cause-and-effect diagram of hypothetical events. Analysis of fault trees is used to investigate failures in a system or concept.
fertile	Describes a nuclide that can be transmuted into a fissile nuclide by absorption of a neutron and subsequent decay.
filter bank	An arrangement of air filters in series and/or parallel.
fissile	Describes a nuclide that undergoes fission on absorption of neutrons of any energy.
fission	The splitting of a heavy nucleus into two approximately equal parts, each the nucleus of a lighter element, accompanied by the release of a large amount of energy and generally one or more neutrons. Fission can occur spontaneously, but it usually follows the absorption of neutrons.
fissionable	Describes a nuclide that undergoes fission on absorption of a neutron of energy over some threshold energy.
fluid inclusion	Brine inclusion. A small opening in a rock mass (salt) containing brine; also the brine included in such an opening. Some gas is often also present.
forb	A non-woody plant that is not grass or grass-like.
formation (geologic)	The basic rock-stratigraphic unit in the local classification of rocks. It consists of a body of rock (usually sedimentary) generally characterized by some degree of internal lithologic homogeneity or distinctive features.
gamma rays	Short-wavelength electromagnetic radiation emitted in the radioactive decay of certain nuclides. Gamma rays are the same as gammas or gamma particles.
gamma-spectrum isotopic analysis	Analysis of the radionuclides present in a sample by measurement of the energy spectrum of gamma radiation emitted.
geothermal gradient	The rate of increase of temperature of the earth with depth. The approximate average value in the earth's crust is 25°C per kilometer or 1.4°F per hundred feet.
getter	A material that selectively sorbs and holds particular nuclides.

glove box	A sealed box in which workers, remaining outside and using gloves attached to and passing through openings in the box, can safely handle and work with radioactive materials.
gross alpha	The total rate of alpha particle emission from a sample, without regard to energy distribution or source nuclide.
gross beta	The total rate of emission of beta particles from a sample, without distinguishing energy distributions or source nuclides.
Gulf interior salt dome region	A region in northeastern Texas, northern Louisiana, and central Mississippi containing several hundred salt domes. Salt domes near or under the Gulf of Mexico are not included. (See map in Figure B-4.)
gypsum	A mineral consisting of hydrous calcium sulfate: $CaSO_4 \cdot 2H_2O$. It is soft and, when pure, is white.
half-life	The time required for the activity of a group of identical radioactive nuclei to decay to half its initial value.
halite	The mineral rock salt: NaCl.
Hanford Site	A 580-mi^2 DOE reservation in southcentral Washington near the Columbia River. The nearest city is Richland, Washington.
health physics	The science concerned with the recognition, evaluation, and control of health hazards from ionizing radiation.
high-level waste	Nuclear waste resulting from reprocessing of spent fuel. Discarded, unreprocessed spent fuel is also high-level waste. It is characterized by intense, penetrating radiation and by high heat-generation rates. Even in protective canisters, high-level waste must be handled remotely.
hundred-year storm	A storm that, on a statistical basis, is only expected to recur once every hundred years.
hydraulic conductivity	A quantity defined in the study of groundwater hydraulics that describes the rate at which water flows through an aquifer. It is measured in feet per day or equivalent units. It is equal to the hydraulic transmissivity divided by the thickness of the aquifer.
hydraulic gradient	A quantity defined in the study of ground-water hydraulics that describes the rate of change of head with distance of flow.

hydraulic potential (or hydraulic head)	Hydraulic pressure corrected for the potential energy of elevation. In an aquifer it is equivalent to the highest level of a column of water that the pressure in the aquifer will support. It is measured relative to a specified level, in this document sea level.
hydrofracture	A process of producing underground openings by injection of fluids (usually water) at pressures greater than the weight of the overlying rock and soil.
in situ	In the natural or original position. The phrase is used in this document to distinguish in-place experiments, rock properties, and so on, from those in the laboratory.
intensity, earthquake	A measure of the effects of an earthquake on humans and structures at a particular place. Not to be confused with magnitude.
Intermediate Scale Facility (ISF)	A kind of facility proposed by the IRG in which the disposal of up to 1000 spent fuel assemblies would be demonstrated. See the IRG's own words in Appendix C.
interstitial brine	Brine distributed in very small openings throughout a salt mass.
ion exchange	A phenomenon in which chemical species in one phase or material exchange with similar species in another phase. In this report, ion exchange usually refers to a particular process in an aquifer: the exchange of ions in the water for ions in or on the rocks.
irradiation	Exposure to any form of radiant energy.
ISF, stand-alone	An Intermediate Scale Facility whose sole purpose is the demonstration of the disposal of spent fuel.
isotope	A species of atom characterized by the constitution of its nucleus and hence by the number of protons and the number of neutrons in it. In most instances an element can exist as any of several isotopes, differing in the number of neutrons, but not the number of protons, in their nuclei. Isotopes can be either stable isotopes or radioactive isotopes (also called radioisotopes).
langbeinite	A mineral, $K_2Mg_2(SO_4)_3$, used in the fertilizer industry as a source of potassium sulfate.
leaching	The process of extracting a soluble component from a solid by the percolation of a solvent (in this report, water) through the solid.
lithostatic pressure	Underground pressure due to the weight of overlying rock or soil.

Los Medanos	Literally, "little sand bars" in Spanish. In this report, the area surrounding the site proposed for the WIPP reference repository.
magnitude, earthquake	A measure of the total energy released by an earthquake. Not to be confused with intensity.
man-rem	A unit of population dose.
matrix, waste	The material in which radioactive nuclear waste is encapsulated. As used frequently in this document, the term refers to the material, likely to be a glass, encapsulating reprocessed high-level waste and contained in a canister.
Mercalli intensity	A scale of measurement of earthquake intensity.
mined materials	The rock salt and other natural materials brought up to the ground surface during mining.
Nash Draw	A shallow 5-mile-wide valley open to the southwest located to the west of the WIPP reference site. See map in Figure 7-15.
natural background radiation	Radiation in the human environment from naturally occurring elements and from cosmic radiation.
Nevada Test Site (NTS)	An area in Clark and Nye Counties in southern Nevada dedicated to the underground testing of nuclear weapons. The nearest large city is Las Vegas, Nevada.
nuclide	Isotope.
nuclide inventory (radionuclide inventory)	A list of the kinds and amounts of radionuclides in a container. Amounts are usually expressed in activity units: curies or curies per unit volume.
order of magnitude	A factor of ten. When a measurement is made with a result such as 3×10^7, the exponent of 10 (here 7) is the order of magnitude of that measurement. To say that this result is known to within an order of magnitude is to say that the true value lies between (in this example) 3×10^6 and 3×10^8.
overcoring	A process for removing waste from its burial in salt by extracting a cylinder of salt that surrounds and contains the waste.
overpack	A container put around another container. In the WIPP, overpacks will be used on damaged or otherwise contaminated drums, boxes, and canisters that it is not practical to decontaminate.

packer	A device used in drilled holes to isolate geological strata from one another in order to carry out hydrologic studies of particular formations.
Paradox basin	A 10,000-square-mile area in southeastern Utah and southwestern Colorado underlain by a series of salt-core anticlines. See Figure B-3.
Pasquill Stability Category	Relates atmospheric stability to the dispersion of an effluent plume. These categories range from A (extremely unstable: a plume will disperse rapidly) to F (moderately stable: a plume will not appreciably disperse).
permeability	Equivalent to hydraulic conductivity.
Permian basin	A region in the Central United States where, during Permian times 280 to 225 million years ago, there were many shallow seas that laid down vast beds of evaporites. The Delaware Basin is a part of the Permian Basin. See figure B-1.
point source	A source of effluents that is small enough in dimensions that it can be treated as if it were a point. The converse (not used in this document) is a diffuse source. A point source can be either a continuous source or a source that emits effluents only in puffs or for a short time.
population dose	The sum of the radiation doses received by the individual members of a population.
Radiation Protection Guide	The officially determined radiation doses that should not be exceeded without careful consideration. These standards, originally set forth by the ICRP and the NCRP are now part of EPA regulations. They are equivalent to what were formerly called Maximum Permissible Exposures.
radiolysis	Chemical decomposition by the action of radiation.
radwaste	Short for radioactive waste.
reference proposal	In this document, the WIPP reference repository at the reference site, as described in Section 2.3.
reference repository	In this document, a proposed repository for certain types of nuclear waste in southeastern New Mexico. It and the proposed reference site (q.v.) have been studied and analyzed in detail and are therefore the reference base comparative analysis of alternatives.
reference site	In this document, a 30-square-mile site in southeastern New Mexico, 25 miles east of Carlsbad, in terms of which the reference repository has been designed and analyzed.

rem	A unit of individual dose equivalent.
remotely handled waste	Waste that requires shielding in addition to that provided by its container in order to protect people nearby.
repository	A facility for the storage or disposal of radioactive waste.
reprocessing	The process by which spent fuel from a reactor is separated into waste material and uranium and plutonium to be reused as nuclear fuel.
retrievable	Describes storage of radioactive waste in a manner designed for recovery without loss of control or release of radioactivity.
risk	The product of probability and consequence. In this report, the radioactive risk of a scenario is the population dose resulting from that scenario multiplied by the probability that the scenario will actually occur.
Rustler Formation	The evaporite beds, including mudstones, of probable Permian age that immediately overlie the Salado formation in which the WIPP disposal levels are proposed to be built.
Salina region	A region in Michigan, Ontario, Ohio, West Virginia and New York underlain by extensive bedded salt of Paleozoic age. The region is divided into the Michigan and Appalachian basins. See Figure B-2.
Salado Formation	The evaporite formation of Permian age within which it is proposed to dispose of wastes at the WIPP reference repository.
Salt Vault, Project	A field experiment carried out by ORNL between 1965 and 1967 in an abandoned salt mine at Lyons, Kansas. Its purpose was to demonstrate the feasibility and safety of the concept of emplacing high-level waste in salt, to demonstrate equipment and techniques for handling packages of highly radioactive solids, and to secure data for the design of an actual disposal facility. Its results are reported in Bradshaw and McClain (1971).
San Simon Sink	The central, most depressed area of San Simon Swale.
San Simon Swale	A broad depression about 15 miles east of the WIPP reference site, open to the southeast. See Figure 2-2.
scenario	A particular chain of hypothetical circumstances that could, in principle, release radioactivity from a repository.

sector, economic	A distinctive part of the economy of a geographical region, defined by a standard industrial classification scheme. One such scheme defines "major" sectors and divides them into subsectors; for example, the major sector "trade" contains the subsectors "wholesale trade" and "retail trade." Another classification scheme specifies "primary" and "secondary" sectors; the criterion for including a sector in the primary classification is that its level of activity be generally not controlled by the level of economic activity in the region; a primary industry, in other words, produces goods and services for export from the region.
Seismic Risk Zone	A designation of a geographic region expressing the maximum intensity of earthquakes that could be expected there.
shaft	A man-made hole, either vertical or steeply inclined, that connects the surface with the underground workings of a mine.
shaft pillar	The cylindrical volume of rock around a shaft from which major underground openings are excluded in order that they not weaken the shaft.
sorption	The binding on a microscopic scale of one substance to another, such as by adsorption or ion exchange. In the WIPP context, the word is especially used in the sorption of solutes onto aquifer solids.
source term	The kinds and amounts of radionuclides that make up the source of a potential release of radioactivity. See nuclide inventory.
specific activity	Radioactivity per unit weight of radioactive material.
spent fuel	Nuclear-reactor fuel that, through nuclear reactions, has been enough depleted of fissile material to require its removal from the reactor.
storage	Temporary disposition in a repository. Use of the word storage implies keeping open the possibility of retrieving the waste for reprocessing, for moving it elsewhere, etc. Storage usually implies the need for continued surveillance.
storage pool, spent fuel	A water-filled and cooled basin in which spent fuel is stored before being sent away for reprocessing or disposal.
study area	The region about the WIPP reference site studied in the evaluation of that site.
sylvite	A mineral, KCl, used as a fertilizer.
thermal excursion	A transient change in temperature or in heat output.

thermal field	The field or set of temperatures throughout a volume. Use of the term usually connotes temperatures that differ from point to point.
thermal gradient	The rate of change of temperature in the direction of increasing temperature.
transmissivity, hydraulic	A quantity defined in the study of ground-water hydraulics that describes the rate at which water may be transmitted through an aquifer. It is measured in ft^2/day or equivalent units.
transuranic nuclide	A nuclide with an atomic number greater than that of uranium (92). All transuranic nuclides are produced artificially and are radioactive.
TRU waste	Waste with specific transuranic alpha activity of 10 nCi/g or greater. This waste can vary greatly in its specific gamma activity.
tuff	A rock formed of compacted volcanic ash and dust. It is usually porous and often soft.
wind rose	A diagram showing the distribution with direction of the frequency and/or speed of the wind.

Abbreviations and Acronyms

AACC	American Association for Contamination Control
ACGIH	American Congress of Government Industrial Hygienists
AEC	U.S. Atomic Energy Commission
AFR	Away from reactor (spent fuel storage)
AMAD	Aerodynamic mean activity diameter
AMP	Allotment Management Plan: a BLM term
AMS	Aerial measuring systems
ANSI	American National Standards Institute
AQCR	Air Quality Control Region (of EPA)
ARMS	Aerial radiological measurement surveys
ATMX	Atomic munitions transport car (a rail car used for transporting CH TRU waste)
AUM	Animal-unit month: a term used by the Bureau of Land Management
BBER	Bureau of Business and Economic Research, University of New Mexico
BLM	Bureau of Land Management, Department of the Interior
BOD	Biological oxygen demand
CAB	Civil Aeronautics Board
CFR	Code of Federal Regulations
CH	Contact handled; used as of low-level waste not requiring shielding or the facilities for handling
DEIS	Draft Environmental Impact Statement
DOE	U.S. Department of Energy
DOI	U.S. Department of the Interior
DOT	U.S. Department of Transportation
EAR	Environmental Analysis Record: a term used by the BLM
ECS	Environmental control system
EEG	Environmental Evaluation Group, New Mexico
EIS	Environmental Impact Statement
EMT	Emergency medical technician
ENMU	Eastern New Mexico University, Portales, N.M.
EPA	U.S. Environmental Protection Agency
ERDA	U.S. Energy Research and Development Administration
ESCNM	Employment Security Commission of New Mexico
ESSA	Environmental Science Services Administration (now replaced by the National Oceanic and Atmospheric Administration)
FHA	Federal Housing Authority
FR	Federal Register
FRA	Federal Railroad Administration
FWPCA	(U.S.) Federal Water Pollution Control Administration
FWS	Fish and Wildlife Service, Department of the Interior
GAO	General Accounting Office
GEIS	Generic Environmental Impact Statement
GESMO	GEIS on mixed oxide fuels

HEPA	High-efficiency particulate air; a type of filter
HIAP	Hobbs Industrial Air Park
HLW	High-level waste
HUD	U.S. Department of Housing and Urban Development
IMCC	International Minerals and Chemical Corporation
INEL	Idaho National Engineering Laboratory
IRG	Interagency Review Group on Nuclear Waste Management
ISF	Intermediate Scale Facility
LASL	Los Alamos Scientific Laboratory, New Mexico
L_{eq}	Probable sound energy average
MFP	Management Framework Plan; a term used by the BLM
mgd	Million gallons per day
MM	Modified Mercali (scale of earthquake intensity)
MTU	Metric tons of uranium
NAAQS	National ambient air quality standards
NAS-NRC	National Academy of Sciences-National Research Council
NCC	National Climatic Center
NCRP	National Council on Radiation Protection and Measurements
NEPA	National Environmental Policy Act of 1969
NMBM&MR	New Mexico Bureau of Mines and Mineral Resources
NMDFA	New Mexico Department of Finance and Administration
NMDGF	New Mexico Department of Game and Fish
NMEI	New Mexico Environmental Institute
NMEID	New Mexico Environmental Improvement Division
NMHD	New Mexico Highway Department
NOAA	National Oceanic and Atmospheric Administration
NOS	National Oceanic Survey
NPDES	National Pollution Discharge Elimination Administration
NRC	U.S. Nuclear Regulatory Commission
NTS	Nevada Test Site
NUREG	Identifier on NRC documents
NWS	National Weather Service; formerly U.S. Weather Bureau
NWTSP	National Waste Terminal Storage Program
ONWI	Office of Nuclear Waste Isolation, Battelle Memorial Institute, Columbus, Ohio
ORNL	Oak Ridge National Laboratory, Tennessee
OSTP	Office of Science and Technology Policy
OWI	Office of Waste Isolation, Union Carbide Corporation, Oak Ridge, Tennessee
PL	Public Law
ppm	Parts per million
PWR	Pressurized-water reactor
RH	Remotely handled; used as of waste requiring shielding or of waste containers or waste-handling facilities
RFP	Rocky Flats Plant, Denver, Colo.
RMA	Recreational market area

RPG	Radiation Protection Guide
RWMC	Radioactive Waste Management Complex at the Idaho National Engineering Laboratory
scfm	Standard cubic feet per minute
SCS	Soil Conservation Service, Department of Agriculture
SPL	Sound-pressure level
SPSC	Southwestern Public Service Company
SRP	Savannah River Plant, South Carolina
TDS	Total dissolved solids
TLD	Thermoluminescent dosimeter
TRU	Transuranic; refers to nuclides beyond uranium in the periodic table
TSA	Transuranic Storage Area at Idaho National Engineering Laboratory
T22S, R31E	Township 22 South, Range 31 East
URA	Unit Resource Analysis; a term used by BLM
USAEC	United States Atomic Energy Commission
USBM	United States Bureau of Mines
USC	United States Code (of laws)
USDA	United States Department of Agriculture
USDI	United States Department of the Interior
USEPA	United States Environmental Protection Agency
USERDA	United States Energy Research and Development Administration
USGS	United States Geological Survey
USNRC	United States Nuclear Regulatory Commission
WACSC	Waste Acceptance Criteria Steering Committee
WIPP	Waste Isolation Pilot Plant
WISAP	Waste Isolation Safety Assessment Program

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